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The Effect of Resin Binder Additions on the Properties of Molding Sands

By Emile Pragoff, Jr.* and C. P. Albus**, Wilmington, Dela.

Abstract

Studies are presented on the effect of additions of a pulverized high melting pine resin on the physical properties of two synthetic bonded molding sands. The effects of other variables in mold making, such as ramming, drying temperature, air-drying and storage in a moist atmosphere, are studied. The effect of resin binder addition to molding sand may be summed up as follows: The resin imparts added dry strength to the sand beyond that normally expected from the clay alone. The sand containing resin, when air-dried, will show a higher mold hardness and will reach this hardness sooner. When fully dried, the resin bonded sand will retain its dry compression strength better when exposed to moist atmosphere. When subjected to heat during pouring, the resin is decomposed, generating an appreciable volume of gas of a reducing character. The resin loses bond rapidly, as shown by hot strength tests. The resin had little effect on expansion of two sands examined. The addition of resin reduced the tendency of a synthetic bonded sand to crack on shock heating. Photographs illustrating this effect are included. Some data on the effect of other organic materials as additions to molding sand are included. A method for determining gas evolution of molding sands when heated is described, and apparatus illustrated. Graphs presenting the data are appended as well as photographs of the testing equipment.

1. In 1939 some information was presented to the Association on the properties of cores bonded with resin binder[1]. This informa-

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** Chemist, Hercules Experiment Station.
1 Superior numbers refer to bibliography item numbers at end of paper.
Note: This paper was presented at a Sand Research Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 24, 1942.

tion was well received and widely used by foundrymen who applied this knowledge to use resins successfully in a variety of core work.

2. The purpose of this paper is to study the effect of resin binder additions on the physical properties of molding sand. Many foundrymen are familiar with the effect of other organic materials in molding sand. For those who are not, as well as to illustrate the relative magnitude of the effect of resin binder additions, some comparative data on other organic binders are included. These materials are added to molding sands for the reason that their use helps produce sound castings of better finish.

3. Cereal binders are most commonly added to synthetic bonded steel molding sands, while sea coal is common to iron foundry sands. Pitch is used in both iron and steel foundry dry sands. Opinions differ on the manner in which these materials function. Cereal binders are said to improve workability, to increase dry strength, and to affect the surface qualities of molds developed by air-drying. Sea coal is believed to have more complicated actions[2], involving the creation of a reducing atmosphere in the mold, the formation of a carbon coating on the sand grains, and a "cushioning effect" caused by temporary reduction in permeability.

4. These better-known materials have served foundrymen well. It is our hope that this work, by providing a better understanding of the action of resins in molding sand, may help the foundrymen produce better molds and better castings.

RESIN BINDERS

5. Resins may be divided into two groups, natural and synthetic. Natural resins occur in nature in special cavities in plant life, while synthetic resins are those produced by chemical reaction. Because of their cost, synthetic resins have not been widely used as a binder for core or molding sands. Natural resins, readily available at a low cost, have found wide usage.

6. The most abundant natural resins are those obtained from pine trees. The following are several types of pine resin: Gum rosin is obtained by tapping the living tree and distilling the gum which exudes; wood rosin is obtained by solvent extraction of shredded pine stump wood; limed wood rosin is obtained by treating wood rosin with lime which raises the melting point and renders the resin more soluble in petroleum thinners. This resin, as

well as gum rosin and untreated wood rosin, has been widely used as an ingredient of core oils. So also has heat-treated wood rosin, which is obtained by carefully controlled heat treatment of wood rosin.

7. Beginning in 1935 there was made available to foundries a pine resin having a character somewhat different from the other pine resins. This new resin was higher in melting point and different from ordinary wood rosin in that it was obtained by extracting pine stump wood with solvents other than gasoline. This resin was found to be more suitable for use as a dry core binder because of its low ash, high melting point, and higher bonding strength. It can be pulverized readily to the desired fineness to give easy mixing with core or molding sands. When pulverized its melting point is sufficiently high that it can be shipped and stored in powdered form without danger of reversion. This type resin has been used by many foundries in a wide variety of core work. A study of its effect when added to molding sand is given to represent the effect of resins as a class.

Table 1

SCREEN ANALYSES OF SANDS USED*

	Per Cent Retained on Sieve	
Sieve No.	*Silica Sand*	*Lake Sand*
6	0.0	0.0
12	0.0	0.0
20	T**	0.1
30	0.2	0.5
40	1.0	2.8
50	5.3	11.5
70	28.5	51.8
100	41.7	31.1
140	18.5	1.9
200	4.1	0.2
270	0.4	0.0
Pan	0.2	T**
Total	99.9	99.9
Fineness No.	71.6	55.4
Grain Shape	Subangular	Subangular

* Sands screened as received.
** T—denotes trace.

MATERIALS USED

8. The sands used in this investigation were:

1. Silica sand, grain fineness No. 72.
2. Michigan City sand, grain fineness No. 55. The screen analyses of these sands appear in Table 1.

9. The resin binder utilized in this work meets the following specifications:

	Minimum	*Maximum*
Drop melting point	230°F.	239°F.
Acid number	95	
Gasoline insoluble content	95%	
Screen analysis—Material passing 30 mesh	100%	—
Material passing 80 mesh	90%	—
Material passing 200 mesh	60%	80%

When pulverized to this fineness the resin will weigh 4 lb. per gal.

10. The cereal binder was a cereal of the yellow type, which weighed 4.75 lb. per gal. The sea coal and pitch used in this investigation are considered representative of the materials used commercially. Table 2 shows data on the screen analyses of these organic materials. Western and southern bentonite were employed in this investigation.

Table 2

SCREEN ANALYSES OF ORGANIC MATERIALS USED

	Per Cent Retained on Sieve		
Sieve No.	*Sea Coal*	*Pitch*	*Resin*
6	0.0	—	—
12	0.0	—	—
20	2.0	—	—
30	13.0	0.4	0.0
40	16.9	—	—
50	14.1	—	—
70	12.3	—	—
80	—	15.8	0.7
100	10.8	—	—
140	7.9	—	—
200	5.9	57.8	36.3
270	3.5	—	—
Pan	13.0	26.0	63.0
Total	99.4	100.0	100.0

Table 3

CHEMICAL ANALYSIS OF ORGANIC MATERIALS

	Sea Coal	*Pitch*	*Resin*	*Cereal A*	*Cereal B*
Ash (per cent)	7.98	0.10	0.05	0.01	0.10
Total volatile (per cent)	29.81	19.11	86.52	96.47	86.94
Fixed carbon (per cent)	63.21	80.79	13.43	3.52	12.96

11. In ash content, resins are low, as are pitch and cereal. In total volatile matter, resins are much higher than either pitch or sea coal; they are about the same as cereals. In fixed carbon content, resins are low, compared with sea coal and pitch. A second cereal binder was examined, and was found to differ appreciably from the other cereal in volatile matter and fixed carbon.

CONDITIONS OF TESTS

12. Synthetic bonded molding sand compositions were prepared which would be comparable to those used in steel and iron foundry practice. The basic sand compositions selected were:

Steel Foundry Sand

Silica sand (fineness No. 72)	95 parts by weight
Western bentonite	5 parts by weight
Moisture	4 per cent ± 0.1 per cent

Organic additions:

(1) Resin binder—1 per cent by weight—(equal to 1-33 by volume)
(2) Cereal binder—1 per cent by weight—(equal to 1-40 by volume)

Iron Foundry Sand

Lake sand (fineness No. 55)	95 parts by weight
Western bentonite	2.5 parts by weight
Southern bentonite	2.5 parts by weight
Moisture	4 per cent ± 0.1 per cent

Organic additions:

(1) Resin —1 per cent by weight—(equal to 1-33 by volume)
(2) Pitch —2 per cent by weight—(equal to 1-20 by volume)
(3) Sea coal —5 per cent by weight—(equal to 1-10 by volume)

VARIABLES AFFECTING MOLDING SAND PROPERTIES

13. Many factors affect the physical properties of molding sand. In order to show the effect which the addition of resin binder would produce, we endeavored to hold certain variables to small limits and alter others. Control tests were made throughout, using

the respective clay-bonded sand to which no organic material was added. In most cases, comparative data were obtained showing the effect of adding the other organic materials.

14. The variables studied were:

(1) Effect of resin binder additions on the green and dry physical properties of molding sand.
(2) Effect of ramming on the properties of molding sand containing resin binder.
(3) Effect of air-drying on the properties of molding sand containing resin binder.
(4) Effect of storage in moist atmosphere on the strength of dry sand molds containing resin binder.
(5) Effect of oven temperature during baking on the dry strength of dry sand molds containing resin binder.
(6) Effect of resin binder additions on the hot strength, expansion, etc. of molding sand.
(7) Effect of resin binder additions on gas evolution from green and dry molding sand during pouring.
(8) Visual observations on the effect of resin binder addition on the reaction of molding sand to thermal shock.

15. In our work, we did not endeavor to determine the optimum moisture content for the sand compositions tested. This question has been studied extensively for bentonite bonded steel sands by Briggs and Morey[3]. Individual considerations in each foundry determine what shall be considered optimum moisture conditions for efficient operation. Nor did we endeavor to determine optimum mulling time for the sand compositions examined. Considerable work has been done on this question by such investigators as A. H. Pierker[4] and others.

16. In this connection, however, it should be pointed out that any foundry or laboratory making studies on molding sand compositions should determine the optimum mulling time for the size of muller employed. The 18-in. dia. laboratory muller used in these experiments was equipped with the newer type cross head which insures the intensive mixing of the materials without piling up in front of the plow. In all cases, moisture was held to 4.0 per cent $\pm$ 0.1 per cent. Variation in the moisture content of a molding sand mix would probably alter the rate of change of physical properties to a lesser degree in the case of finer sands such as the steel foundry sand, having a grain fineness of 72. It would have

a greater effect in the case of the iron foundry sand, having a fineness of 55.

TESTING PROCEDURES

17. Most of the testing procedures applied in this work are set forth in the standard and tentative standard procedures of the AMERICAN FOUNDRYMEN'S ASSOCIATION Subcommittee on Sand Tests (TESTING AND GRADING OF FOUNDRY SAND AND CLAYS—Fourth Edition, 1938). There is at present no tentative standard procedure for hot strength tests. This is also true in the case of the expansion determinations and gas evolution tests. Our procedures for these will be described later in detail.

18. In the preparation of molding sand specimens, the following procedure was employed: Forty-five hundred gr. batches of dry materials were placed in an 18-in. laboratory size mixer. In all mixes the sand plus clay substance totaled 4500 gr. Organic binders added were based on percentage of the total sand plus clay weight. Moisture was then added and reported as percentage of total weight. The dry binders were weighed and added to the dry sand. Dry mixing was done for a period of 1 min. and wet mixing for a period of 5 min. This was found to be sufficient for the size of batch and type of bond employed. After mixing, the batches were discharged from the mixer into 2-gal. pails fitted with friction tops.

19. Moisture determinations were made on a portion of the mix using a moisture teller. In our laboratory this instrument is controlled by rheostat to give a temperature of 105-110°C. It was found that this instrument would dry 50-gr. samples of moist molding sand thoroughly in 5 min. The ramming of test specimens was accomplished by means of the standard A.F.A. rammer. In the case of most specimens these were 2-in. x 2-in. cylinders which were single end rammed. In the case of the specimens for hot strength and expansion tests these were 2-in. x 1⅛-in. cylinders which were double end rammed with the rammer for this size specimen.

20. The specimens were dried in a core oven of our own design, which in general meets the requirements of the Association. This oven is shown in Fig. 1. Heating is provided by resistance heaters. The oven is equipped with a blower for blowing warm air from the heating chamber into the oven. It is equipped with 2 rotating

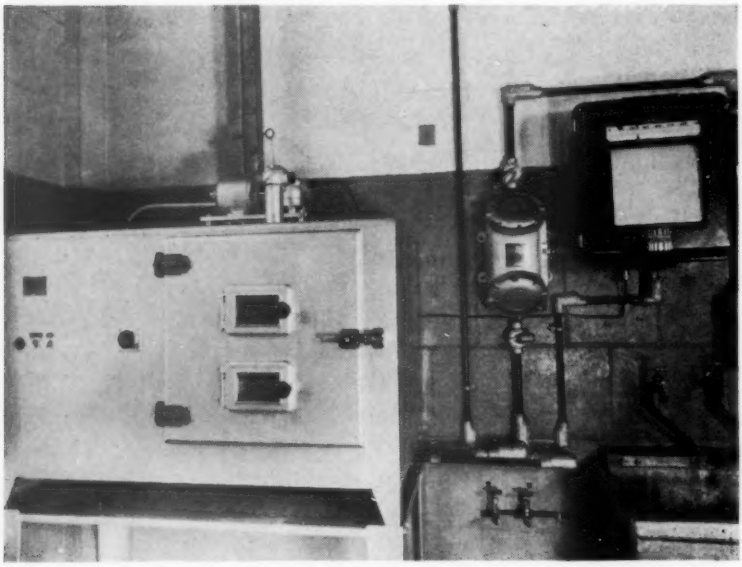

FIG. 1—LABORATORY CORE OVEN.

shelves which will carry a large number of specimens. Change in oven atmosphere is controlled by 2 vents on the oven. Temperature is controlled by thermostat to ± 2°F. and recovery to desired temperature is rapid. This oven was equipped with a recording, indicating, and controlling pyrometer.

21. Such elaborate equipment is not necessary for control work. However, a recording pyrometer will always show how quickly the oven regained the desired temperature. It will also show any irregularities caused by power failure, etc. It is thus more useful for research work on foundry sands. The operating range of this oven was from 150°F. to 650°F. After drying, the dry sand core specimens were allowed to cool in desiccators which contained calcium chloride. This was done because of the tendency of dried molding sand specimens to absorb moisture from the atmosphere rapidly and lose dry strength.

DISCUSSION OF TEST RESULTS

22. Since the character of steel foundry molding sands is rather different from that of iron foundry molding sands, discussion of test results is naturally divided into these two logical sections.

EFFECT OF RESIN BINDER ADDITION ON THE PROPERTIES OF STEEL FOUNDRY MOLDING SANDS

23. In Table 4 is shown the effect of adding 1 per cent of resin binder to silica sand bonded with 5 per cent bentonite by weight. For purposes of comparison, similar data are included illustrating the effect of the addition of 1 per cent cereal binder to the same silica sand-bentonite composition.

Table 4

EFFECT OF RESIN BINDER ADDITION ON PHYSICAL PROPERTIES OF STEEL FOUNDRY MOLDING SAND

Materials—Parts by Weight	*No. 1*	*No. 2*	*No. 3*
Silica sand	95	95	95
Bentonite	5	5	5
Cereal binder	—	1	—
Resin binder	—	—	1
Moisture (per cent)	4.1	4.0	3.9
Green compression strength (lb. per sq. in.)	5.1	7.0	6.4
Green permeability	111	115	102
Flowability	85	77	82
Deformation (in./in.)	0.017	0.027	0.018
Resilience	87	189	115
Mold hardness	75	82	80
Dry compression strength (lb. per sq. in.)	133	113	170
Dry permeability	146	163	138

24. The addition of resin binder had the following effect:

Green strength (lb. per sq. in.)	—increased from	5.1	to	6.4
Green permeability	—decreased from	111	to	102
Flowability	—decreased from	85	to	82
Deformation (in./in.)	—no change	0.017	to	0.018
Resilience	—increased from	87	to	115
Mold hardness	—increased from	75	to	80
Dry compression strength	—increased from	133	to	170
Dry permeability	—decreased from	146	to	138

25. The principal effect of the resin binder addition was that of increasing considerably the dry sand strength. This is brought about by a cementing action of the resin particles distributed among and between the clay coated sand grains. The resin is not

water soluble, nor does it swell in water as do cereals. Hence, its noticeable effect on green strength is probably brought about by an increase in green frictional strength rather than green cohesive strength. The resin offers increased resistance to the sliding of sand grains, one over another. The greater dry strength of the mold containing a resin addition should be a factor in producing cleaner castings.

EFFECT OF RAMMING

26. Modern foundry practice has directed attention toward the more uniform ramming of molds. We studied the effect of ramming through determinations made on specimens which were rammed respectively, 3, 6, 9, 12, and 15 blows of the standard rammer. These 2-in. x 2-in. cylindrical specimens were stripped from the ramming tube by inverting the tube. Mold hardness determinations were made by means of a mold hardness tester on the surface of the specimen which was face down during ramming. Specimens were weighed on a balance to the nearest 0.1 gr. The height of each rammed specimen was determined by placing on each specimen a thin metal disc, then placing the specimen under a dial gauge calibrated to 0.001-in. By means of the formula below, the green apparent density was determined.

$$\text{Green apparent density} = \frac{\text{weight of green specimen}}{\text{volume of green specimen}}$$

$$\text{Since volume} = \pi r^2 h$$
$$\text{then green apparent density} = \frac{W}{3.1416\ (1)^2 h}$$

The formula may be further simplified to:

$$\text{Density} = \frac{\text{weight in gr.}}{\text{h (in.)} \times 3.1416 \times (1)^2 \times (2.54)^3}$$

or

$$\text{Density} = \frac{\text{weight in gr.}}{\text{h (in.)} \times 51.7}$$

27. This density will read gr. per cu. cm. It is felt that by this method we arrive at a more accurate measure of green apparent

density than by endeavoring to ram exactly to a height of 2-in. After determining the height, a green compression test was made on the same specimens. Dry sand tests were made on specimens whose density had been determined while in the green state. Results of these tests are shown graphically in Figs. 2, 3, 4, 5, and 6.

28. In Fig. 2, it will be seen that as molding sand containing bentonite alone is rammed harder the permeability decreases. This also holds true when the molding sand contains 1 per cent resin. The effect of 1 per cent cereal is to increase slightly the permeability of a bentonite bonded sand, when it is rammed 3 rams. This effect is apparently lost when molds are rammed harder; *i.e.*, 6 rams or more. In Fig. 3, the effect of ramming on green compression strength is shown. Green strength increases with degree of ramming. The effect holds true for steel molding sands to which either resin or cereal is added. In Fig. 4, we show the effect of ramming on the green apparent density of these sand mixes.

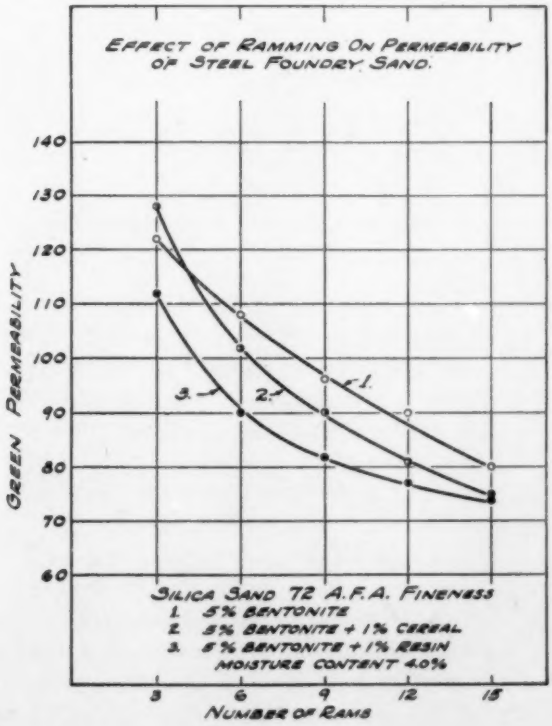

FIG. 2—EFFECT OF RAMMING ON PERMEABILITY OF STEEL FOUNDRY MOLDING SAND.

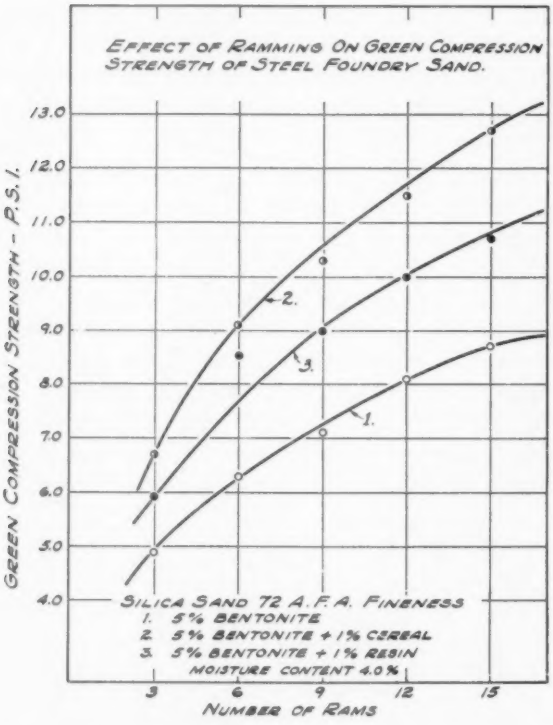

FIG. 3—EFFECT OF RAMMING ON GREEN COMPRESSION STRENGTH OF STEEL FOUNDRY MOLDING SAND.

The addition of 1 per cent resin decreases the density slightly.

29. In Fig. 5 is shown the effect of ramming on mold hardness. A bentonite bonded steel sand required 9 rams to reach mold hardness of 85. When 1 per cent resin was added to this sand, it reached 85 mold hardness in 6 rams. Cereal binder produces a comparable effect. For a given number of rams the sand containing resin produced higher mold hardness than that containing clay alone.

30. In Fig. 6 is shown the effect of ramming on dry compression strength. Increasing the number of rams from 3 to 6, raised the dry strength of the bentonite bonded sand from 122 to 154 lb. per sq. in. In the sand containing the addition of 1 per cent resin binder, the added ramming increased the dry strength from 183 to 229 lb. per sq. in. Thus we have the possibility of making use of ramming and of resin binder additions to greatly increase the

dry strength of dry sand molds. This effect of ramming carries over into the hot strength[5] of such sands. Further tests are to be made along such lines. Since many foundries use equipment for ramming molds which gives a higher hardness than is obtained with 3 rams of the standard rammer, this may suggest that when evaluating clays, dry binders, etc., attention should be paid to the mold hardness normally required in the foundry and specimens be rammed accordingly. This would probably give a truer picture of the action of the sand under operating conditions.

EFFECT OF DRYING TEMPERATURE ON PROPERTIES OF STEEL FOUNDRY SANDS

31. Many foundries add organic materials to their molding

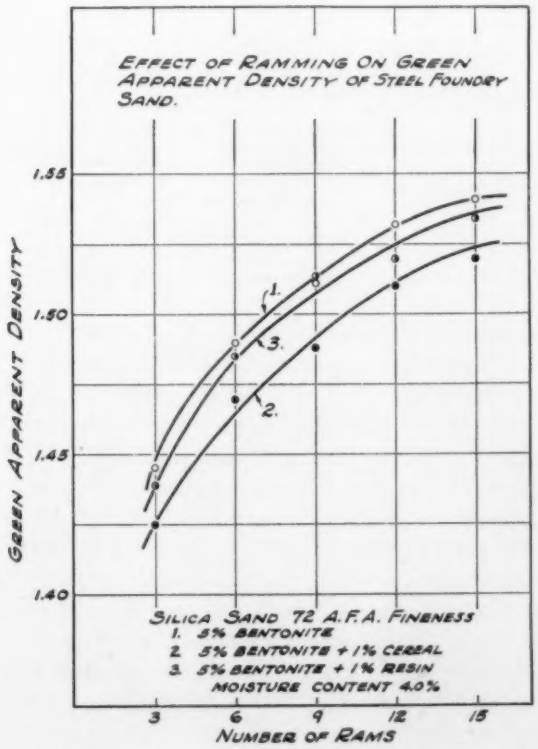

FIG. 4—EFFECT OF RAMMING ON GREEN APPARENT DENSITY OF STEEL FOUNDRY MOLDING SAND.

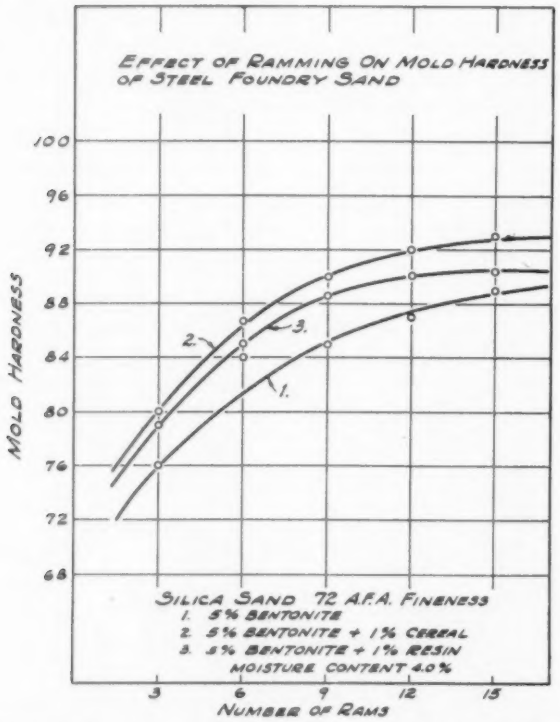

FIG. 5—EFFECT OF RAMMING ON MOLD HARDNESS OF STEEL FOUNDRY MOLDING SAND.

sand compositions to impart additional strength to those molds which are dried in the oven or those which are torch-dried on the surface or skin-dried. In Table 5, we present data illustrating the effect of drying 2-in. x 2-in. laboratory specimens for 2 hours each at temperatures of 230, 400, 500 and 600°F. Comparative data are presented for a steel sand containing bentonite alone, one containing bentonite plus 1 per cent resin binder and one containing bentonite plus 1 per cent cereal binder. As the temperatures increased from 230° to 600°F., little change occurred in the dry strength of bentonite bonded sand. In the case of the sand containing the resin binder, the dry strength increased from 170 lb. at 230°F. to 209 lb. at 400°F., increasing further to 223 lb. at 500°F., and finally falling to 200 lb. per sq. in. at 600°F. The comparative data for the composition containing cereal show that as the drying temperature is increased, the dry strength decreases steadily up to 500°F. and rapidly thereafter.

32. From these tests, as well as from previous tests on such resins in cores, we see that baking at 500°F. brings out the full effect of the resin on dry strength. Dry sand molds dried below that temperature would not reach optimum strength. Similarly, a dry sand mold dried at that temperature would probably retain more resistance to the metal entering the mold than would a mold which had been dried at any other temperature. Some of the above heated specimens were used for hot strength determinations at 500°F. using a dilatometer. (See paragraphs 41, 42 and 43 for method.) We find that where the resin binder was added in proportion of 1 per cent by weight, the effect on the hot strength at 500°F. did not show up until the resin had been hardened by baking at temperature of 500°F. We present this data to illustrate the rather large differences which can occur, depending upon the conditions of drying of molds.

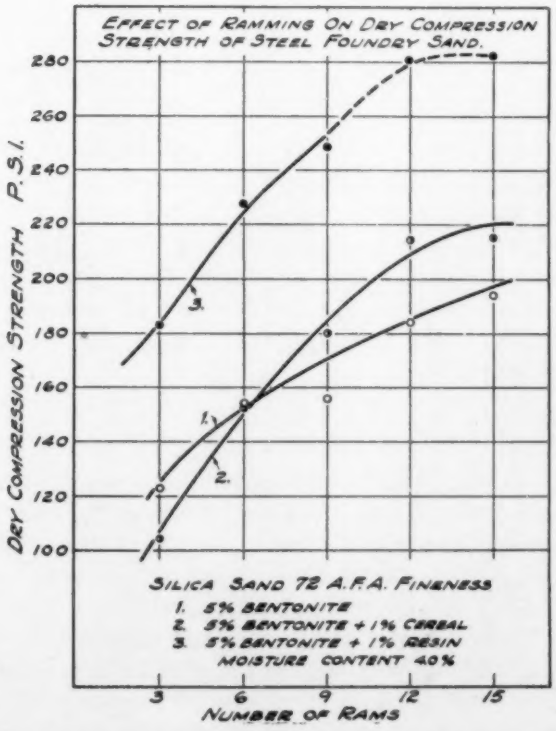

FIG. 6—EFFECT OF RAMMING ON DRY COMPRESSION STRENGTH OF STEEL FOUNDRY MOLDING SAND.

Table 5

EFFECT OF BAKING TEMPERATURE ON DRY COMPRESSION STRENGTH OF STEEL FOUNDRY MOLDING SAND

Materials—Parts by Weight	*No. 1*	*No. 2*	*No. 3*
Silica sand	95	95	95
Bentonite	5	5	5
Cereal binder	—	1	—
Resin binder	—	—	1
Moisture (per cent)	4.1	4.0	4.0
Dry Compression Strength (2-in. x 2-in. specimens)			
Dried 2 hours @ 230°F.	132	113	170
Dried 2 hours @ 400°F.	122	104	209
Dried 2 hours @ 500°F.	138	101	223
Dried 2 hours @ 600°F.	129	81	200
Hot Strength at 500°F. (1⅛-in. x 2-in. specimens)			
Dried 2 hours @ 230°F.	120	97	107
Dried 2 hours @ 400°F.	103	87	117
Dried 2 hours @ 500°F.	118	92	175
Dried 2 hours @ 600°F.	102	70	183

33. Although a clear picture of the properties of sands containing a clay alone may be obtained by drying at 230°F., this work suggests that when evaluating a molding sand containing an organic binder, a better picture is obtained by drying the specimens at the optimum temperature for the sand examined. This temperature will depend upon the nature of the ingredients in the sand composition.

EFFECT OF AIR-DRYING ON THE PROPERTIES OF STEEL SANDS

34. Many foundries have found it expedient to allow small molds to air-dry on the floor for several hours. This has the effect of reducing the moisture content of the face of the mold, increasing the mold hardness. Such molds have been said to produce castings having less sand adhering to metal. In Table 6 we have presented data on this effect of air-drying the 3 sand compositions described above. We followed the effect of air-drying by observations on the green compression strength and mold hardness. Green specimens were allowed to air-dry by storing at 70°F. and 65 per cent relative humidity. We find that for a straight bentonite

Table 6

EFFECT OF AIR-DRYING ON THE PROPERTIES OF STEEL FOUNDRY MOLDING SANDS*

Materials—Parts by Weight	*No. 1*	*No. 2*	*No. 3*
Silica sand	95	95	95
Bentonite	5	5	5
Cereal binder	—	1	—
Resin binder	—	—	1
Moisture (per cent)	4.0	4.0	3.9
Green Compression Strength (lb. per sq. in.)			
As rammed	4.8	6.4	6.2
After 1 hour air-drying	8.1	9.6	10.1
After 2 hours air-drying	12.5	12.1	14.1
After 8 hours air-drying	29.3	28.5	29.0
After 24 hours air-drying	42	39	42
After 48 hours air-drying	47	48	48
After 72 hours air-drying	48	50	54
Mold Hardness			
As Rammed	70	73	74
After 1 hour air-drying	92	94	95
After 2 hours air-drying	93	95	95
After 8 hours air-drying	93	95	95
After 24 hours air-drying	93	95	95

bonded sand, the green compression strength increases from 4.8 lb. to 12.5 lb. on air-drying for 2 hours. The addition of 1 per cent resin alters this effect only slightly, the green strength increasing from 6.2 to 14.4 lb. per sq. in. A similar rise was observed in the case of the composition containing cereal binder. Air-drying for longer periods increased the green strength further. However, the effect of resin or cereal was found to be slight, as illustrated in Fig. 7.

35. Similar observations on mold hardness showed that all three sands increased in mold hardness from 70 to at least 92 in 1 hour and to 93 or more in 2 hours. Those compositions containing resin binder or cereal binder gave slightly harder molds at all times, reached 95 in 2 hours. Further storage had little effect on mold hardness. This indicates that the sand containing resin binder should be useful to foundries using green sand practice, since this composition gives higher mold hardness in shorter time of air-drying.

* Green specimens air-dried @ 70°F. and 65 per cent relative humidity.

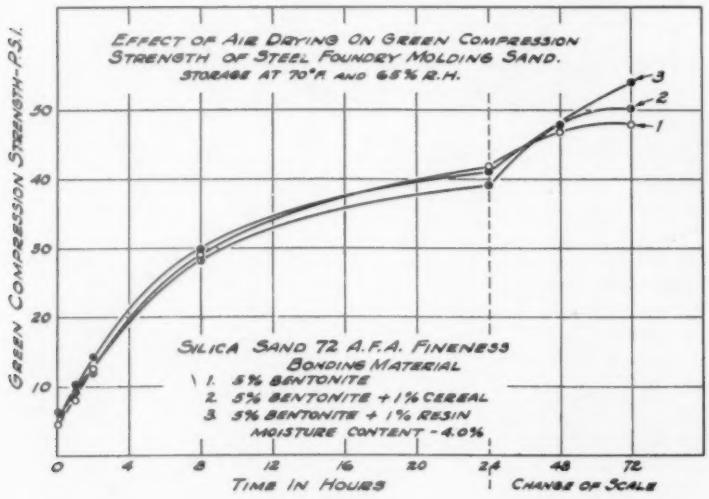
EFFECT OF AIR DRYING ON GREEN COMPRESSION STRENGTH OF STEEL FOUNDRY MOLDING SAND.
STORAGE AT 70°F. AND 65% R.H.
GREEN COMPRESSION STRENGTH-P.S.I.
SILICA SAND 72 A.F.A. FINENESS
BONDING MATERIAL
1. 5% BENTONITE
2. 5% BENTONITE + 1% CEREAL
3. 5% BENTONITE + 1% RESIN
MOISTURE CONTENT - 4.0%
TIME IN HOURS
CHANGE OF SCALE

FIG. 7—EFFECT OF AIR-DRYING ON THE GREEN COMPRESSION STRENGTH OF STEEL FOUNDRY MOLDING SAND.

Table 7

EFFECT OF STORAGE IN MOIST ATMOSPHERE ON THE DRY COMPRESSION STRENGTH OF STEEL FOUNDRY MOLDING SANDS

Materials—Parts by Weight	*No. 1*	*No. 2*	*No. 3*
Silica sand	95	95	95
Bentonite	5	5	5
Cereal binder	—	1	—
Resin binder	—	—	1
Moisture (per cent)	4.0	4.0	4.0
(Specimens were dried 2 hours @ 230°F., cooled in desiccator)			
Dry Compression Strength (lb. per sq. in.)			
After 0 hour exposure*	133	113	169
After 1 hour exposure*	62	67	137
After 2 hours exposure*	61	58	105
After 4 hours exposure*	48	58	105
After 8 hours exposure*	46	52	93
After 24 hours exposure*	42	54	85
After 48 hours exposure*	44	54	72
After 72 hours exposure*	45	55	67

* At 70°F. and 65 per cent relative humidity.

EFFECT OF ATMOSPHERE ON DRY STRENGTH OF STEEL FOUNDRY SANDS

36. It has been demonstrated by English investigators[6, 7] and observed by many foundrymen that a mold which has been dried in an oven, on being allowed to stand in air, will lose its dry compression strength and hardness, absorbing moisture from the atmosphere. We endeavored to show the effect of resin binder on this phenomenon. In Table 7 and Fig. 8 are shown data obtained by exposing a number of dried specimens at 70°F. and 65 per cent relative humidity. It will be seen that the various sand compositions all fell in compression strength rather rapidly during the first 4 hours of exposure, the rate of fall decreasing thereafter. In the case of bentonite, the strength fell from an initial strength of

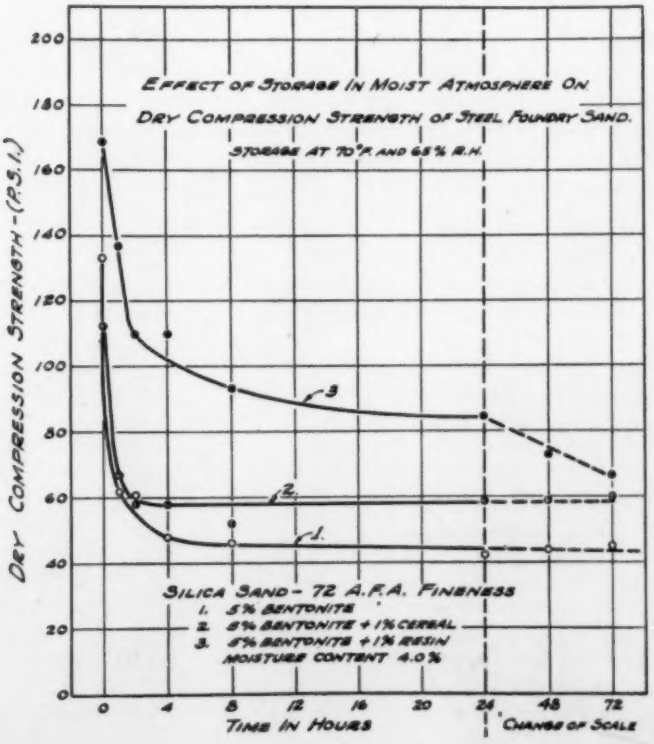

FIG. 8—EFFECT OF STORAGE IN MOIST ATMOSPHERE ON THE DRY COMPRESSION STRENGTH OF STEEL FOUNDRY MOLDING SAND.

133 lb. per sq. in. to 48 lb. per sq. in. in 4 hours. The composition containing bentonite plus 1 per cent of resin binder fell from 169 lb. per sq. in. to 105 lb. per sq. in. in the same period of time, while that containing bentonite plus 1 per cent cereal binder fell from 113 lb. per sq. in. to 58 lb. per sq. in. This is a rather clear-cut argument for drawing up a more specific standard procedure to be employed in dry sand tests. Present procedure* simply requires that specimens be allowd to cool to room temperature.

37. In order to determine the actual amount of moisture absorbed by the respective compositions, a number of tests were made in which dried specimens were weighed both before and after storage in the constant humidity room. The results appear in Table 8. These show that after 2 hours, the compositions had absorbed about 0.27 per cent moisture by weight. After 8 hours, they had absorbed about 0.45 per cent, and after 24 hours, about 0.55 per cent by weight. This absorption of water is caused by the clay present in the sand. It should be pointed out that whereas the resin binder did not alter the tendency to absorb moisture, the actual absorption of that moisture had less effect on the strength of the bentonite-resin composition than on the straight bentonite composition. This would prove valuable in skin-drying of molds. The use of 1 per cent resin in molding sands dried with a torch

Table 8

EFFECT OF STORAGE IN MOIST ATMOSPHERE ON MOISTURE ABSORPTION OF STEEL AND IRON FOUNDRY MOLDING SANDS**

	Per Cent Moisture Absorbed by Weight		
	2 Hours	*8 Hours*	*24 Hours*
Steel Foundry Sands Bonded With			
(a) 5 per cent bentonite	0.23	0.42	0.55
(b) 5 per cent bentonite + 1 per cent cereal	0.27	0.49	0.62
(c) 5 per cent bentonite + 1 per cent resin	0.26	0.43	0.52
Iron Foundry Sands Bonded With			
(d) 2.5 per cent western bentonite 2.5 per cent southern bentonite	0.29	0.58	0.65
(e) 2.5 per cent western bentonite) 2.5 per cent southern bentonite) + 5 per cent sea coal	0.34	0.58	0.70
(f) 2.5 per cent western bentonite) 2.5 per cent southern bentonite) + 2 per cent pitch	0.33	0.52	0.63
(g) 2.5 per cent western bentonite) 2.5 per cent southern bentonite) + 1 per cent resin	0.33	0.54	0.60

* TESTING AND GRADING FOUNDRY SANDS AND CLAYS, Section X, pp. 189-190.

** Dried specimens stored @ 70°F. and 65 per cent relative humidity. This atmosphere contains 1.03 per cent moisture by weight.

or given a quick oven drying would cause the molds to retain strength better after such drying.

EFFECT OF RESIN BINDER ADDITION ON THE PROPERTIES OF IRON FOUNDRY MOLDING SANDS

38. In Table 9, we show the effect of adding respectively, 1 per cent resin binder, 2 per cent pitch, and 5 per cent sea coal, on the green and dry properties of a lake sand bonded with 2½ per cent each of western bentonite and southern bentonite. It will be seen that the addition of resin increases slightly the green compression strength and decreases the permeability. It has only slight effect on flowability and on deformation. It increases the mold hardness obtained with 3 rams. The principal effect of adding a resin binder to such sands is shown in the large increase in dry compression strength. The sand plus clay had a dry compression strength of 112 lb. per sq. in. The addition of 1 per cent resin increased dry strength to 190 lb. per sq. in. Comparative data on pitch and sea coal showed the relative effect of these materials. The large effect observed for sea coal is probably a function

Table 9

EFFECT OF RESIN BINDER ADDITION ON PROPERTIES OF IRON FOUNDRY MOLDING SANDS

Materials—Parts by Weight	*No. 1*	*No. 2*	*No. 3*	*No. 4*
Lake sand	95.0	95.0	95.0	95.0
Western bentonite	2.5	2.5	2.5	2.5
Southern bentonite	2.5	2.5	2.5	2.5
Sea coal	—	5.0	—	—
Pitch	—	—	2.0	—
Resin binder	—	—	—	1.0
Moisture (per cent)	4.1	4.0	3.9	3.9
Green compression strength (lb. per sq. in.)	6.6	7.7	8.9	8.0
Green permeability	167	122	127	139
Flowability	83	82	82	81
Deformation (in./in.)	0.019	0.015	0.020	0.017
Resilience	125	116	178	136
Mold hardness	79	84	84	83
Dry compression strength (lb. per sq. in.)	112	164	197	190
Dry permeability	205	156	185	193

of the fineness of the sample examined. Two per cent pitch has about the same effect as 1 per cent resin.

EFFECT OF DRYING TEMPERATURE ON PROPERTIES OF IRON FOUNDRY SANDS

39. In Table 10 are given data showing the effect of drying 2-in. x 2-in. specimens from the above iron foundry sands for 2 hours each at temperatures of 230, 400, 500, and 600°F. These data show that the drying temperature had little effect on the strength of the sand containing clay alone. In the sand containing 1 per cent resin binder, optimum dry strength was obtained in specimens

Table 10

EFFECT OF BAKING TEMPERATURE ON DRY COMPRESSION STRENGTH OF IRON FOUNDRY MOLDING SANDS

Materials—Parts by Weight	*No. 1*	*No. 2*	*No. 3*	*No. 4*
Lake sand	95	95	95	95
Western bentonite	2.5	2.5	2.5	2.5
Southern bentonite	2.5	2.5	2.5	2.5
Sea coal	—	5	—	—
Pitch	—	—	2	—
Resin binder	—	—	—	1.0
Moisture (per cent)	4.0	4.0	4.0	4.0
Dry compression strength (lb. per sq. in.)				
Dried 2 hours @ 230°F.	108	158	197	178
Dried 2 hours @ 400°F.	122	168	197	192
Dried 2 hours @ 500°F.	117	160	204	191
Dried 2 hours @ 600°F.	118	124	203	153

baked at 400 to 500°F. The sand containing sea coal showed an optimum drying range of from 400° to 500°F. and that containing pitch showed optimum drying range of 500° to 600°F.

EFFECT OF ATMOSPHERE ON DRY STRENGTH OF IRON FOUNDRY SANDS

40. Tests were made on the effect of storage in moist atmosphere on the dry compression strength of iron foundry molding sands. These tests were conducted in the same fashion as those on the steel foundry sands previously described. Data appear in Table 11 and graphically in Fig. 9. It is noted that the dry compression

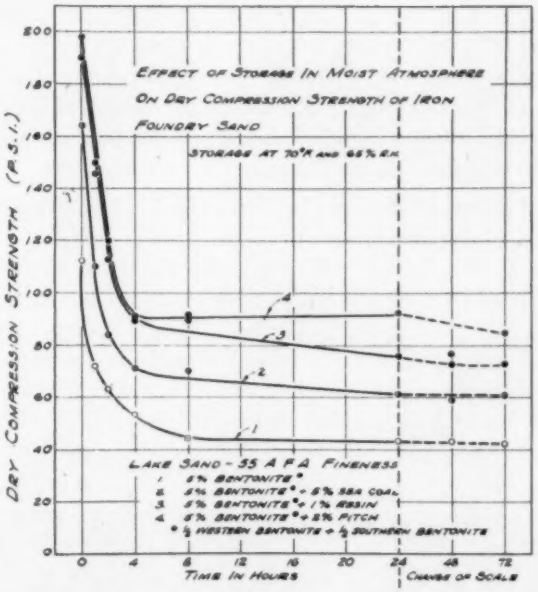
EFFECT OF STORAGE IN MOIST ATMOSPHERE
ON DRY COMPRESSION STRENGTH OF IRON
FOUNDRY SAND
STORAGE AT 70°F AND 95% R.H.
DRY COMPRESSION STRENGTH (P.S.I.)
TIME IN HOURS
CHANGE OF SCALE
LAKE SAND - 55 A.F.A. FINENESS
1. 6% BENTONITE*
2. 6% BENTONITE* + 6% SEA COAL
3. 6% BENTONITE* + 1% RESIN
4. 6% BENTONITE* + 2% PITCH
* ½ WESTERN BENTONITE + ½ SOUTHERN BENTONITE

FIG. 9—EFFECT OF STORAGE IN MOIST ATMOSPHERE ON THE DRY COMPRESSION STRENGTH OF IRON FOUNDRY MOLDING SAND.

strength of such sands falls rapidly during the first few hours of storage. This drop in strength levels off after 24 hours. These tests showed that in such a sand, the addition of resin binder maintained the strength at a higher level than in a sand containing no resin binder. This effect might be beneficial to those iron foundries utilizing skin-dried mold technique. Skin-dried molds containing resin binder should retain their strength qualities better than those containing no organic addition. Two per cent of pitch appears to give about the same effect as 1 per cent resin binder.

HOT STRENGTH TESTS

Equipment

41. The effect of resin binder additions on the hot strength of steel and iron foundry sands was determined. These tests were made using a dilatometer. This instrument, which is illustrated in Fig. 10, consists of a furnace heated with a heating element, capable of reaching a temperature of 2850°F. The heat in the furnace is regulated by means of a transformer equipped with jack plugs. The recording, indicating, and controlling pyrometer is

also shown in Fig. 10. We found this type pyrometer particularly effective in that it permits the close control of furnace temperature with the minimum amount of attention on the part of the operator. In this type work, the use of a recording pyrometer also provides some insurance against change in furnace temperature without the operator becoming aware of this change.

42. Considerable precautions are taken in our laboratory to prevent accidents which would cause injury to a person using the equipment or to the equipment proper. In the main 440-volt line providing current to the transformer, we installed a circuit breaker designed for operation up to 35 amps. In the same line, we installed a manual starter which was fused for 30 amps: thus, if the heating elements drew in excess of 30 amps., the manual starter would kick out. This had the effect of protecting both the transformer and the heating elements. We placed a small switch on the

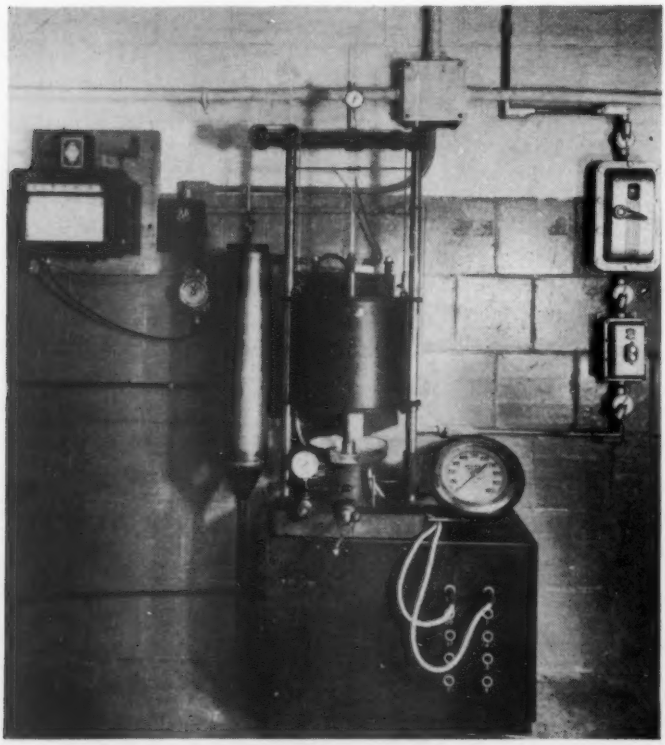

FIG. 10—DILATOMETER AS SET UP FOR EXPANSION TEST.

Table 11

EFFECT OF STORAGE IN MOIST ATMOSPHERE ON DRY COMPRESSION STRENGTH OF IRON FOUNDRY MOLDING SANDS

Materials—Parts by Weight	*No. 1*	*No. 2*	*No. 3*	*No. 4*
Lake sand	95	95	95	95
Western bentonite	2.5	2.5	2.5	2.5
Southern bentonite	2.5	2.5	2.5	2.5
Sea coal	—	5	—	—
Pitch binder	—	—	2	—
Resin binder	—	—	—	1
Moisture (per cent)	3.9	4.0	3.9	4.0
(Specimens were dried 2 hours @ 230°F. cooled in desiccator)				
Dry compression strength (lb. per sq. in.)				
After 0 hour exposure*	112	164	197	190
After 1 hour exposure*	72	110	146	150
After 2 hours exposure*	63	84	113	120
After 4 hours exposure*	53	71	91	91
After 8 hours exposure*	44	70	90	92
After 24 hours exposure*	43	61	92	76
After 48 hours exposure*	43	59	78	73
After 72 hours exposure*	42	61	85	73

110-volt line between the controller and the relay contactor. This permitted cutting out the controller from this operation and made it possible for us to use it on other operations, either as an indicating or recording pyrometer. The relay contactor actuates the primary of the transformer in turn, causing the elements to heat up in the furnace.

Method

43. In these hot strength tests, there is at present no standard procedure. In our work, all specimens were rammed with the 1⅛-in. specimen rammer. Specimens were double end rammed. They were dried at 230°F. for 2 hours, were removed from the oven, and placed directly into a desiccator where they were allowed to stand until cool. In making the hot strength tests, the dilatometer was first raised to the desired temperature; for example, 500, 1000, 1500, 2000, or 2500°F. In all cases, the temperature was controlled to ± 15°F. A specimen was placed in the furnace and allowed to

* At 70°F. and 65 per cent relative humidity.

Table 12

EFFECT OF RESIN BINDER ADDITION ON THE HOT STRENGTH OF STEEL MOLDING SANDS

Materials—Parts by Weight	*No. 1*	*No. 2*	*No. 3*
Silica sand	95	95	95
Bentonite	5	5	5
Cereal binder	—	1	—
Resin binder	—	—	1
Moisture (per cent)	4.1	4.0	3.9
Dry compression strength (lb. per sq. in.)			
2-in. x 2-in. cylinder*—dried 2 hours @ 230°F.	133	113	170
1⅛-in. x 2-in. cylinder—dried 2 hours @ 230°F.	147	150	206
Hot strength** @ 230°F.	142	110	190
Hot strength** @ 500°F.	120	97	107
Hot strength** @ 1000°F.	121	71	158
Hot strength** @ 1500°F.	275	177	225
Hot strength** @ 2000°F.	424	297	348
Hot strength** @ 2500°F.	12	10	17
Specimens heated 15 minutes at 800°F., then cooled to room temperature	127	83	149

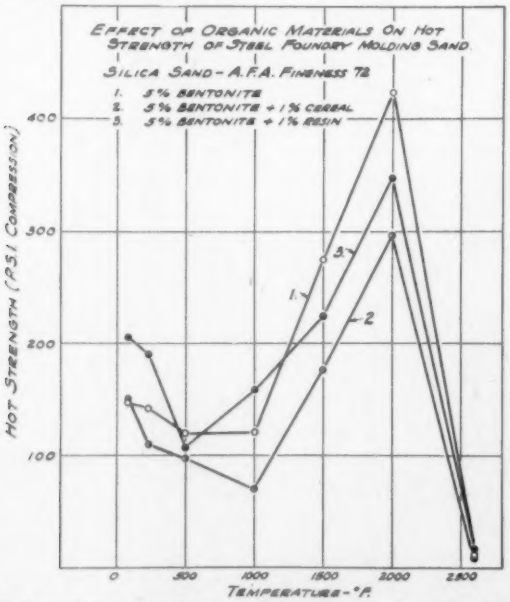

FIG. 11—EFFECT OF ORGANIC MATERIALS ON HOT STRENGTH OF STEEL FOUNDRY MOLDING SAND.

* Denotes single end rammed specimens.

** Hot strength data not corrected for weight of piston and post.

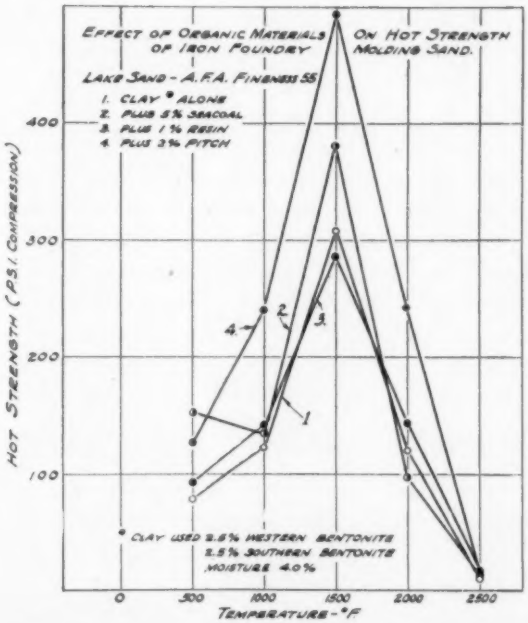

FIG. 12—EFFECT OF ORGANIC MATERIALS ON HOT STRENGTH OF IRON FOUNDRY MOLDING SAND.

soak for 15 min. The specimen was then broken in compression stress. We endeavored to apply load at the rate of 100 lb. per min. Some difficulty was encountered obtaining uniform rate of loading. However, we found rather good checks obtained following this procedure.

HOT STRENGTH DATA ON STEEL FOUNDRY SANDS

44. The data are given in Table 12 and Fig. 11. It should be noted that no relation exists between the 2-in. x 2-in. single end rammed specimen which is used for dry sand tests and the 2-in. x 1⅛-in. double end rammed specimen used for hot strength tests. In the hot strength test, we find that a specimen at 500°F. had lower compression strength than it had at room temperature. As the temperature was increased the bentonite bonded steel foundry sand increased in strength reaching a peak at 2000°F., falling rapidly thereafter. This same shape curve was obtained when the steel foundry sand contained either a resin or a cereal binder. The organic material, however, lowered the peak strength

reached at 2000°F. At the highest temperature of test, 2500°F., very slight differences were observed in the 3 sands examined. There is a tendency toward plasticity in sand specimens at this temperature.

45. Our conclusion is that resins or other organic binders have little effect on the hot strength at 2500°F. The addition of resin lowered the peak hot strength of a bentonite bonded sand. This might help relieve stresses caused by use of a sand of too high a hot strength. In Table 12, we also show the effect of heating specimens from each sand for 15 min. at 800°F., then cooling to

Table 13

EFFECT OF RESIN BINDER ADDITION ON THE HOT STRENGTH OF IRON FOUNDRY MOLDING SANDS

Materials—Parts by Weight	*No. 1*	*No. 2*	*No. 3*	*No. 4*
Lake sand	95.0	95.0	95.0	95.0
Western bentonite	2.5	2.5	2.5	2.5
Southern bentonite	2.5	2.5	2.5	2.5
Sea coal	—	5	—	—
Pitch	—	—	2	—
Resin	—	—	—	1
Moisture (per cent)	4.0	4.0	4.1	3.9
Dry compression strength (lb. per sq. in.)				
2-in. x 2-in. cylinders dried 2 hours @ 230°F.	118	181	213	208
1⅛-in. x 2-in. cylinders	—	—	—	—
Hot strength*—green specimens				
@ 230°F.	—	—	—	—
500	118	153	120	92
1000	145	176	234	145
1500	308	418	456	310
2000	226	81	255	134
2500	10	11	12	13
Dry specimens				
@ 500°F.	78	153	127	93
1000	123	135	241	143
1500	317	382	492	287
2000	119	98	242	144
2500	10	11	13	13
Strength on cooling from 800°F.	103	138	273	230

* Hot strength data not corrected for weight of piston and post.

room temperature and breaking at that temperature. This is believed to simulate conditions existing in a part of the mold which has been subjected to considerable heat during and after pouring.

HOT STRENGTH DATA ON IRON FOUNDRY SANDS

46. Hot strength tests were made on the iron foundry molding sands following the same technique. The basic iron foundry sand compositions were employed. A lake sand bonded with 2½ per cent each of Southern and Western bentonite and tempered with 4 per cent moisture was found to have a maximum hot strength at 1500°F. The data which were obtained on dry specimens appear in Table 13 and Fig. 12. These tests show that the addition of 1 per cent of a resin binder did not change the hot strength appreciably at any elevated temperature. These tests were made with a 15 min. heating period, which at elevated temperatures is long enough to destroy the bond developed by the resin. At 2500°F., both sands showed a low dry strength and a tendency toward considerable plasticity.

47. A similar test on a sand containing 2 per cent of pitch showed that the hot strength was increased above that obtained by clay alone. This shows up at all temperatures from 500° to 2000°F. In the case of the addition of 5 per cent sea coal, we find that the hot strength at 1500°F. is increased over that of clay alone. However, at 2000°F. the hot strength of the sand containing sea coal had dropped rapidly. At 2500°F. we find little difference in any of the sands, all showing a rather low hot strength. However, we noticed a considerable difference in the way the specimens broke at 2000°F. This would be tied up with the hot deformation. We have not yet completed hot deformation determination on these sands. Hot strength data are also given for tests made on green specimens of the same sand mixes. In general, these showed good agreement with the dry sand specimens.

EXPANSION AND CONTRACTION

48. Using the dilatometer, we endeavored to determine the effect of a resin binder addition on the expansion and contraction of steel and iron foundry molding sands. Before making expansion and contraction determinations, the quartz rod is so attached to the coil spring at the top of the dilatometer that there will be a 4-oz. load exerted on the specimen during the contraction determina-

tion. Several different procedures were tried in order to eliminate the difficulties caused by expansion of furnace parts. The following was adopted. The furnace is raised to 2500°F. While raising the temperature, the furnace is in the lower position. The furnace is allowed to stand at 2500°F. for a period of 5 min. to insure the lower refractory post has assumed furnace temperature. The furnace is then raised, and a sand specimen introduced into the furnace, placing it on the lower post. The quartz rod and dial gauge are adjusted. The furnace is then lowered. The operation of raising and lowering the furnace should not take over 30 seconds. A stop watch is started as soon as the furnace is lowered. Readings are made on the dial gauge every 15 seconds during the first 2 min., every 30 seconds for the next 3 min., and every min. thereafter, up to 10 min.

49. This procedure was found to give a blank of 0.002-in. after heating for 2 min., decreasing to about 0.001-in. after heating for 10 min. It was found that in all cases where expansion tests were made on dry sand specimens, the furnace recovered to 2500°F. in approximately 2½ min. In the steel foundry sand expansion tests, maximum expansion readings occurred after 1½ min. of heating. Contraction appeared to set in from then on and the lowest expansion readings were obtained at 10 min. heating. This procedure is slightly different from that suggested by the manufacturer of the equipment. However, it gives about the same expansion reading. It probably gives a different contraction figure as shown by our data.

DATA FOR STEEL SANDS

50. With the 4-oz. load, we found 0.018-in. per in. expansion for the silica sand bonded with 5 per cent bentonite. This is the same figure reported by Ehrhart[8]. His tests were made on specimens whose expansion was not hindered. The addition of resin or cereal binder to the bentonite bonded silica sand appeared to have little effect on its expansion. In Table 14 are given the expansion and contraction data on the steel foundry sands and on the iron foundry sands. It will be seen that in no case did contraction of the steel foundry sand occur to sufficient extent to give a negative reading on the dial gauge. In the case of the iron foundry sand, negative readings were obtained with 3 out of 4 sands examined.

Table 14

EXPANSION AND CONTRACTION DATA*

Steel Foundry Sands	*Expansion in. per in.*	*Contraction in. per in.*
Silica sand bonded with		
(1) 5 per cent western bentonite	+ 0.018	+ 0.011
(2) 5 per cent western bentonite + 1 per cent resin	+ 0.017	+ 0.008
(3) 5 per cent western bentonite + 1 per cent cereal	+ 0.016	+ 0.006

Lake Sand	*Expansion in. per in.*	*Contraction in. per in.*	*Green App. Density*
(1) 2.5 per cent western bentonite) 2.5 per cent southern bentonite)	+ 0.018	— 0.023	1.509
(2) 2.5 per cent western bentonite) 2.5 per cent southern bentonite) + 1 per cent resin	+ 0.017	— 0.015	1.513
(3) 2.5 per cent western bentonite) 2.5 per cent southern bentonite) + 2 per cent pitch	+ 0.015	— 0.013	1.518
(4) 2.5 per cent western bentonite) 2.5 per cent southern bentonite) + 5 per cent sea coal	+ 0.014	+ 0.003	1.497

It appears that organic binders may affect the contraction of such sands, since they alter the readings obtained.

DATA FOR IRON SANDS

51. In the iron foundry sands, an expansion of about 0.018-in. per in. and a contraction of 0.023-in. per in. were obtained with a lake sand bonded with 2½ per cent southern bentonite and 2½ per cent Western bentonite. When 1 per cent resin binder was added to this composition, the expansion was decreased by only 0.001-in. per in. The contraction, however, was decreased by 0.008-in. per in. The addition of 2 per cent pitch decreased expansion from 0.018 to 0.015-in. per in. and decreased contraction from 0.023 to 0.013-in. per in. The addition of 5 per cent sea coal decreased expansion from 0.018 to 0.014-in. per in. It also affected contraction to such a degree that a positive reading of 0.003-in. per in. was obtained.

* All tests on specimens dried for 2 hours @ 230°F. Specimens subjected to shock heating at 2500°F. Maximum expansion occurred after 1½ min. Maximum contraction in steel sands occurred after 5 min. Maximum contraction in iron sands had not been reached in 10 min., but test ended.

This latter observation checks some early data determined with this type instrument by Dietert and Valtier[9].

52. It is our feeling that additional tests must be made to establish the effect of such organic materials on expansion and contraction. At the concentrations of resin binder tested, the addition of resin binder had little effect on expansion. As far as contraction is concerned, it appears that contraction may begin to go on sufficiently rapid to be affected by the resin or other organic material as it is burning out.

EFFECT OF RESIN BINDER ON GAS EVOLUTION OF MOLDING SANDS

53. Some information was obtained on the effect of resin binder additions on the relative noncondensable gas evolved by heating molding sands. Comparative data were also obtained on other organic materials. Other investigators of this property of sand have tried various methods to arrive at a significant figure. Briggs and Morey[3] use a procedure which collected the gas by displacement of water. Their procedure, however, measured both condensable and noncondensable gases. Dietert[10] reported some data on the gas evolution of baked foundry cores. He did not describe the method or state whether the gas reported was condensable or noncondensable.

54. The equipment which is illustrated in Fig. 13 consists of

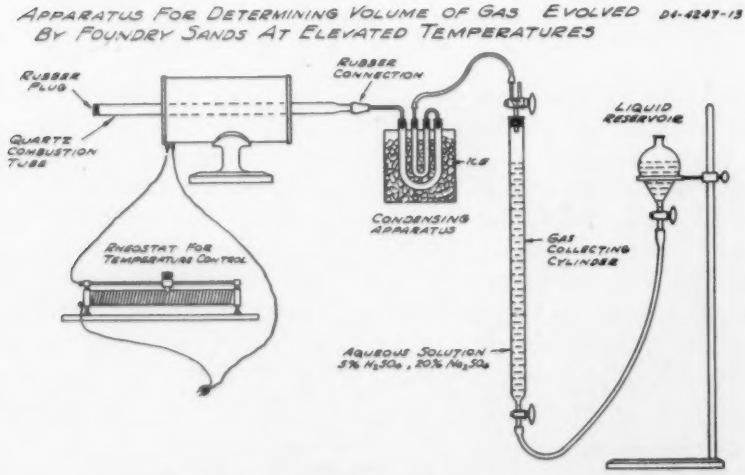

FIG. 13—EQUIPMENT FOR MEASURING GAS EVOLUTION OF FOUNDRY SANDS WHEN HEATED TO ELEVATED TEMPERATURE.

a combustion tube and furnace equipped with a rheostat so adjusted that the furnace would be at 1850°F. To the combustion tube was attached an ice water condenser for the purpose of condensing any condensable gases. The water condenser in turn was attached to a gas collecting chamber graduated in cu. cm. To the bottom of the gas collecting chamber is connected a reservoir by means of heavy rubber tubing. The reservoir and gas collecting tubes were filled with an aqueous solution containing 20 per cent sodium sulphate and 5 per cent sulphuric acid. This liquid was chosen because such gases as carbon monoxide and dioxide have a low solubility in it. The function of the leveling bulb or water reservoir is to balance the pressure inside the combustion tube and gas collecting tube with that of the atmosphere.

55. The procedure employed was as follows:

The liquid level in the gas collecting chamber was set at zero by adjusting the reservoir. A 10-gr. sample of the sand to be tested was weighed into a nickel boat, which was inserted into the hot portion of the tube held at 1850°F. The open end of the tube was immediately stoppered with a soft rubber stopper. As the liquid in the collecting chamber was forced down, the reservoir was lowered to balance pressure. Readings were taken at various time intervals, beginning 15 seconds after the introduction of the sample and continuing up to a total time of 7½ min. It was felt that the accuracy of the method did not justify correcting the gas volume to standard conditions. After each determination, the combustion tube and collecting tube were flushed with air.

56. Three or more determinations were made on each sand examined. A summary of the data obtained appears in Table 15. Blank determinations were made on the sand containing no organic additions. The dry specimens containing silica sand and bentonite showed no gas evolution. The addition of 1 per cent resin gave 5.35 cu. cm. per gr. One per cent cereal binder produces about the same volume of gas. In the case of the green sand specimens, the silica sand containing bentonite gave a negative reading at the end of 7½ min. heating. This was, therefore, added to the relative reading obtained with resin and cereal, respectively. This showed the green gas evolution for a steel foundry sand containing 1 per cent resin to be 6.2 cu. cm. per gr.; 1 per cent cereal under the same conditions produced 6.5 cu. cm. per gr.

57. In the iron foundry sands examined, all tests were made on dry sand specimens. Here the sands plus clay gave a reading of

Table 15

EFFECT OF RESIN BINDER ADDITION ON THE GAS EVOLUTION OF MOLDING SANDS

Composition Steel Facing Sands	*Observed Volume Cu. cm. per gr.*	*Gas Evolution* Cu. cm. per gr.*
Dry—95 per cent silica sand + 5 per cent bentonite	0.0, 0.0	—
95 per cent silica sand + 5 per cent bentonite + 1 per cent cereal	+ 5.0, + 5.0	5.0
95 per cent silica sand + 5 per cent bentonite + 1 per cent resin	+ 5.4, + 5.3	5.35
Green—95 per cent silica sand + 5 per cent bentonite	— 2.1, — 2.1	
95 per cent silica sand + 5 per cent bentonite + 1 per cent cereal	+ 4.5, + 4.3	6.5
95 per cent silica sand + 5 per cent bentonite + 1 per cent resin	+ 3.9, + 4.3	6.2
Iron Foundry Sands		
Dry—95 per cent lake sand — 2.5 per cent western bentonite 2.5 per cent southern bentonite	+ 1.1, + 1.2	—
95 per cent lake sand + 5 per cent sea coal	+ 16.6, + 16.4	15.35
95 per cent lake sand + 2 per cent pitch	+ 6.1, + 6.0	4.9
95 per cent lake sand + 1 per cent resin	+ 7.7, + 7.6	6.5

* Represents noncondensable gas evolved when 10 gr. samples of sands were heated for 7.5 min. at 1850°F. Corrected for blank on sand alone.

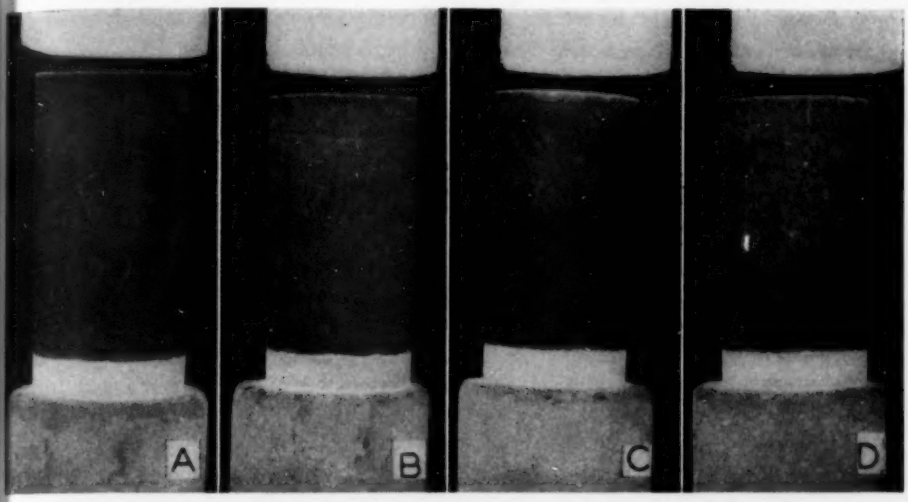

FIG. 14—APPEARANCE OF MOLDING SAND SPECIMENS DURING SHOCK HEATING. SPECIMENS HEATED 15 MIN. AT 2500°F. EXPOSURE MADE 10 SECONDS AFTER FURNACE WAS RAISED. A—SILICA SAND + 5 PER CENT BENTONITE. B—SILICA SAND, 5 PER CENT BENTONITE + 1 PER CENT RESIN. C—SILICA SAND, 5 PER CENT BENTONITE + 1 PER CENT CEREAL. D—LAKE SAND, 2.5 PER CENT SOUTHERN AND 2.5 PER CENT WESTERN BENTONITE.

1.2 cu. cm. per gr. The addition of 1 per cent resin gave 6.5 cu. cm. per gr. corrected gas evolution. The addition of 2 per cent pitch gave 4.9 cu. cm. per gr. The addition of 5 per cent sea coal gave 15.35 cu. cm. per gr.

58. All organic materials generate appreciable gas in either molding or core sands when heated to elevated temperatures. The amount will depend upon the nature of the substance introduced into the sand, the length of time, and the temperature to which the sand is heated. Under the conditions of our test, we notice that some of the sands gave off their gas more rapidly than others. For example, in the first minute of heating, the cereal binder generated 72 per cent of its total gas, the resin, 53 per cent, the sea coal, 41 per cent, and the pitch, 41 per cent. Undoubtedly, the fineness of the sand and of the organic material will have a large effect on the rate of gas evolution.

59. We present this data with the view of encouraging study along this line. We conclude that a resin binder added to molding sands will generate appreciable volume of gas which will help provide a reducing atmosphere. It is our belief that further tests should be made in combustion furnaces in which the atmosphere is

varied from one containing no oxygen to one containing all oxygen. Through such tests we should be able to learn how to control and make better use of these properties of organic materials.

VISUAL OBSERVATIONS ON SANDS SUBJECTED TO SHOCK HEATING

60. The tendency of steel foundry sands to crack on shock heating has been observed by H. L. York[11] in the work of the A. F. A. Subcommittee 6b7. Further investigation of this tendency was made by this committee and reported by J. R. Young[12] in part 2 of their report. Young reported that the larger 2-in. x 2-in. specimen cracked more under shock heating at 2500°F. than did the 1⅛-in. x 2-in. specimen. Also, green specimens cracked more than dried specimens. He further reported that such cracks appeared extensively even in some sands successfully used in gray iron foundries.

61. We endeavored to determine the effect of resin binder addition on the tendency of steel foundry sands to crack under shock heating at 2500°F. The photographs in Fig. 14 illustrate the results obtained on dry specimens. In either green or dried sand specimens, the addition of a resin reduced the number of cracks observed. We made these tests by soaking the respective specimens for 15 min. at 2500°F., then raising the furnace and photographing after about 8 to 10 seconds. The effect of resin and cereal additions may prove of practical foundry application by reducing this tendency to crack under shock heating. We plan to study this further and to include the effect of other organic materials. We found no tendency to cracking in the iron foundry sands examined. However, the iron foundry sands examined showed considerably more tendency toward plasticity or fusion of bond at 2500°F. This was indicated by the fact that iron foundry sands heated for 15 min. at 2500°F., then allowed to cool to room temperature, had assumed a glassy surface and were rather strong. Similarly treated steel foundry sands showed a tendency to crack considerably on cooling and to disintegrate. This effect is shown in Fig. 15.

CONCLUSIONS

62. The limited number of our tests does not justify broad conclusions regarding the effect of resins under all conditions of use in molding sands. However, we can conclude that the addition of resin to a molding sand will:

(1) Increase green strength.
(2) Decrease permeability slightly.
(3) Have little effect on deformation.
(4) Greatly increase dry strength of molding sand.
(5) Increase mold hardness. For a given number of rams, molding sands containing resin are harder.
(6) Impart its maximum effect on dry strength in molds dried at 500°F.
(7) Increase mold hardness developed by air-drying of molds.
(8) Retard loss of strength in dry sand molds exposed to a moist atmosphere.
(9) Affect the hot strength of molding sand. In a bentonite bonded sand, resin lowers peak strength at 2000°F., has little or no effect on strength at 2500°F.
(10) Have little effect on expansion.
(11) Show appreciable effect on contraction, reducing contraction of two sands examined.
(12) Generate appreciable volume of gas during pouring; since such resins are composed of carbon-containing materials, the gases generated are reducing in character.
(13) Reduce tendency to cracking of some sands under shock heating at 2500°F.

63. Only the foundryman can determine whether the addition of resin to his molding sand will improve the quality of his cast-

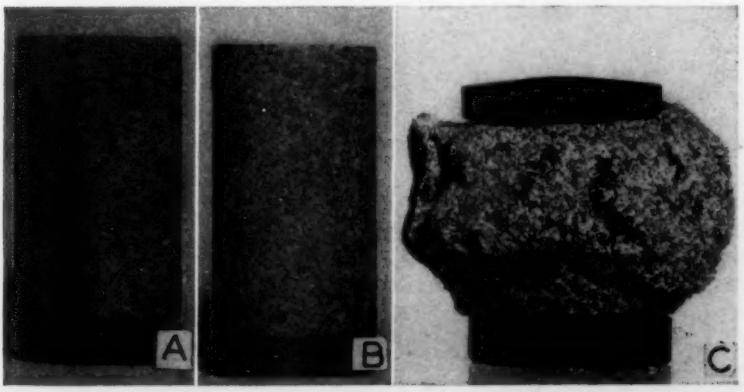

FIG. 15—APPEARANCE OF MOLDING SAND SPECIMENS AFTER SHOCK HEATING AT 2500°F. FOR 15 MIN., THEN COOLING TO ROOM TEMPERATURE. A—SILICA SAND + 5 PER CENT BENTONITE. B—LAKE SAND, 2.5 PER CENT SOUTHERN AND 2.5 PER CENT WESTERN BENTONITE. C—SAME AFTER HOT STRENGTH TEST AT 2500°F.

ings. This work should guide him to a logical use of resins to obtain best results as far as physical properties of sand are concerned. Correlation of castings quality with sand properties will establish the direction in which to work.

PRACTICAL APPLICATION OF RESIN BINDER ADDITIONS TO FOUNDRY MOLDING SANDS

64. These data, determined with new synthethic sands, illustrate the effect of resin binder additions on the properties of such sands. Similar effect is obtained with natural bonded sands. The same basic effect is obtained with system or heap sands, but naturally, the history of the system or heap has important bearing. In most sand systems or heaps there will be some carry-over of unburned organic material added. The sand will gradually change in characteristics, which are controlled by the amount of rebonding materials added. Excessive addition of any rebonding clay or organic material can be harmful. Foundries having no intensive mixing equipment are to be cautioned against adding too much resin binder to their sand heaps. If too much resin binder is added the sand may gradually become "water-proofed" to such a degree that it is not readily wet by water. Resin binder is frequently used in conjunction with other organic materials, such as sea coal, cereal or pitch. Resin binders are being used today by steel and gray iron foundries producing castings in green, skin-dried and dry sand molds.

ACKNOWLEDGMENT

65. The authors wish to acknowledge the assistance of the Hercules Experiment Station photographic department who prepared the photographs and illustrations appearing in this paper.

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DISCUSSION

Presiding: N. J. DUNBECK, Eastern Clay Products, Inc., Eifort, Ohio.
Co-Chairman: C. M. SAEGER, JR., National Bureau of Standards, Washington, D. C.

CHAIRMAN DUNBECK: Mr. Pragoff and Mr. Albus have given us a very interesting paper. They have pointed out that more work along these lines is desirable and that is, of course, true. However, I do feel that their work has been very thorough.

J. B. CAINE: (*written discussion*)[1]: One point should be emphasized that applies not only to this paper but to all reports on the physical properties of sand mixes. The physical properties given apply only to the particular sand mixes studied. Even though other mixes are composed of what seem to be similar materials, any comparison of the results must be made very carefully and the results checked using both types of material.

This point is exemplified in Table 5 of this paper. The authors report compression strengths of 48 lb. per sq. in. for a mix composed of 95 per cent silica sand, 5 per cent western bentonite, 1 per cent cereal binder, and 4 per cent water after air drying for 48 hr. The writer has checked

[1] Sawbrook Steel Castings Co., Lockland, Ohio.

the compression strengths of what should be comparable mixes, using the same proportions of binders and water, but using a different sand and different cereal binders. The compression strengths of these mixes after air drying were all very much higher than those reported in this paper. After 36 to 48 hr., the compression strengths ran from 150 to 200 lb. per sq. in., depending on the type of cereal binder used, although all were corn starch or its derivatives.

A difference of this magnitude, several hundred per cent, cannot be due to a variation in testing technique, and exemplifies the care that must be taken if the physical properties of two sands that seem to be identical are to be compared.

MR. PRAGOFF: We would be very much inclined to agree that the tests should be made in such a way that a direct comparison can be attained, and that those tests should be in turn related to what happens in the foundry.

I do not know at the moment what the conditions of Mr. Caine's tests were, but we found, in making some of our tests, when the humidity changed a bit, it had a marked effect. So we tried to select the humidity test that would be comparable to what was happening from day to day. We selected 65 per cent relative humidity, no circulation in the room. We were fortunate in that we have facilities for making such a test. We felt that if we ran some on a dry day, we would get one result, and, on a wet day, another result. Compression strength rose quickly on a dry day but on a wet day, it did not go up so fast.

MR. CAINE: I think humidity is undoubtedly one of the answers. Sixty-five per cent relative humidity is fairly wet. The specimens I am speaking of were air dried at different times in the foundry over a period of years, and subject to the various humidities and temperatures that existed over that period of time.

We have had consistent results on air drying, and have not had a great deal of trouble due to these variations in the humidity and temperature. The only difference we found was if the temperature was low and the humidity was high, or any combination of those two, air drying is slower. We do not develop the strength as fast, but we do develop it. On a warm, dry day, we will develop maximum strength by air drying within 24 hr., using the 2-in. round A.F.A. specimen. On a cold, damp day, we do not get maximum strength for 48 hr., or in some cases 60 hr. We still get fairly consistent results if we allow the sand to air-dry long enough for the maximum humidity and lowest temperature.

P. J. DAPKUS[2]: In mentioning starch binders, I presume in the work done by Mr. Caine, he used dextrin type binders instead of the more widely used cereal binders, which naturally furnish different results as to green and dry strengths.

MR. CAINE: We used both.

CO-CHAIRMAN SAEGER: Did you use round-grained sands in these studies?

MR. PRAGOFF: The silica sand was a New Jersey silica sand with a 72

[2] Decatur Milling Co., Inc., Decatur, Ill.

grain fineness number. It might be said to be a two-sieve sand. The other sand was a lake sand, and had a grain fineness of about 55.

M. E. GANTZ[3]: Did you make a statement about the percentage of moisture in the atmosphere and its comparison with the amount of moisture that can be picked up in the sand specimen?

MR. PRAGOFF: I believe moisture is like heat. Heat flows from the hotter to the colder. Moisture flows from the most moist material into the least moist material. When we have a dried sand specimen, we place it in a room that has about 1 per cent moisture in the air. Then, if we leave it in there long enough, the sand will pick up moisture to be in equilibrium with the moisture content of air, about 1 per cent. In our case, we did not extend it long enough to reach that point. It picked up about 0.6 per cent, about 60 per cent of the moisture percentage in the air, by weight. We do not know how it is distributed through the sand specimen, but probably most of it was at the surface.

MR. GANTZ: I don't see how you can draw a comparison, or equilibrium, between the moisture in the atmosphere and the amount of moisture contained in the specimen, which contains, not air, but sand and water and clay, or sand and clay. In other words, it is fine to have a small sample of air in a room with 1 per cent moisture. Then the air will pick up the same amount of moisture as existed in the room in which it is exposed, but I think it is wrong to assume that a specimen which is composed of sand and clay can be brought into equilibrium and will contain the same amount of moisture as the air in the room to which it is introduced.

MR. CAINE: We conducted a very unscientific series of experiments on this point. We were worried about moisture pick-up from the atmosphere. We went around and picked up cores which had been stored for some time. Even the cores we knew had been in the foundry for as long as two years contained no more than 0.7 per cent water. This work was done when the weather was cold and damp.

MR. PRAGOFF: Some years ago, this question was raised by a concern which performed some tests on a number of different materials, and their comment was that they picked up a terrific amount of moisture. We asked them the conditions of their tests, and they said they placed these sand cores inside the mold and closed the mold. The cores were not just in contact with air containing 1 per cent moisture, but they were in contact with moist molding sand, which had, say, 5 per cent moisture. It is conceivable that the moisture pick-up would be considerably more than the figure Mr. Caine gave in a closed mold.

MR. GANTZ: I will grant you that the moisture pick-up is dependent on the relative humidity, or, at least, the rate of pick-up, but the absolute maximum pick-up obtained is also dependent on the surface exposed by the sand grains. Flours reach a saturation point much higher than the moisture saturation in the air. Thus, you cannot draw an equilibrium between two very dissimilar materials such as air and sand. One is a solid material, and its moisture absorption is entirely on the surface;

[3] American Magnesium Corp., Cleveland, O.

the air and water vapor mixture is, of course, homogeneous.

CHAIRMAN DUNBECK: The work that we have done is along different lines. We are concerned with a moist tempered sand and how rapidly or how slowly we lose a slight amount of water from that tempered sand. In this discussion, we are dealing with dry materials making a slight pick-up, which is different. I think the point Mr. Pragoff has mentioned is what is called an equilibrium. If you leave samples in a room, the moisture content in those samples will change up and down with the humidity of the room.

E. O. LISSELL[4]: We made some experiments on sand binders a few years ago, to determine the flowability on dry sand specimens without any binder. We dried the specimens, put them in a desiccator and tested the flowability. We found that even in unbonded sand grains, we got a variation in moisture between 0.1 and 0.3 per cent.

MR. PRAGOFF: I believe that if the dry sand is left in a moist atmosphere, it can never have a higher moisture content than the atmosphere. But I do not know whether the adsorption of a material, after it has been dried in a mold, is absolutely dependent on the adsorption before it was dried.

MR. GANTZ: Here is the point I am trying to bring out. Take the question of dry sand as a point in case, and assume it is a sand of 60 grain fineness. I do not know what the amount of air in it actually would be. Assume that there is 30 per cent air in a core made from such sand. Now, the air in that dry core specimen will come up to the same humidity as the air in the room to which it is exposed. In other words, that 30 per cent air in the specimen will achieve a humidity the same as the humidity of the air in the room in which it is placed.

In addition, there is an additional amount of water vapor adsorbed on the surface of the sand grains, depending on several things, the type of grain, the smoothness of grain, etc. The total moisture adsorption is a summation of the two. One is the moisture adsorbed on the surface and the second is the moisture content of the air in that specimen. When clays and colloidal materials are introduced, which actually will retain 2, 3 or 4 per cent moisture indefinitely, a jell is formed, and that jell is stable. In a case like that, the amount of moisture that the specimen absorbs depends on the amount of clay or colloidal material.

An equilibrium is set up, but the percentage of moisture in the air and the percentage of moisture in the specimen cannot be compared.

MR. DAPKUS: Some years ago, I read an A.F.A. paper about the moisture absorption of various materials, and it showed the cereal binders resulted in appreciable loss in strength of the cores. Oil sand cores also lost strength. Other types of binders, such as waste sulphite binders, lost even more strength. Mr. Pragoff has done some work on the moisture absorption of the various binders under different conditions. I do not think that moisture absorption is any great factor in loss of castings as is generally supposed.

MR. PRAGOFF: Our company argued with us because we said that the

[4] Department of Metal Processing, University of Michigan, Ann Arbor, Mich.

resin resists moisture pick-up in the core, and they did not believe it. We got together on it, and they explained that on some cores they left a piece of wax paper to keep the moisture from migrating from the center to the core. I said that if it was necessary to close the molds and let them stand for a while we should pick materials that would do a better job. They said that they had not found anything that did a better job than the resin binders. They have a particular job in which they close the molds on Friday and do not pour them until Monday. There are no materials that I know of that will prevent water from going from the wetter area to the drier area. I would not wish to give the impression that the resin keeps moisture away to that extent. I think that we may have been making tests under one condition and not thinking about the conditions under which the material has to be used, and that is a point to bear in mind all the time.

F. S. BREWSTER[5]: In the magnesium business we were worried more about the effect of the water itself. We stored enough test cores in different places in the foundry so we could break some of them and determine the moisture pick-up. We found that regardless of the type of binder used, the pick-up was nearly always in the range of ¼ to ½ per cent. I have never seen more than ½ per cent pick-up in 48 hr. The difference was not the amount of moisture picked up, but the effect of that water on the different binders. We wanted to see whether certain binders pick up a lot of water because we know water is bad for us.

I assume the water pick-up is chiefly an adsorption on the surface of the grains rather than any binders being deliquescent.

MR. GANTZ: I would like to say that there are some synthetic resins that repel water.

[5] Dow Chemical Co., Bay City, Mich.

The Production of Uniform Steel for a Light Castings Foundry†

By C. H. Kain* and L. W. Sanders*, England

Abstract

A description is given of the routine employed to produce liquid steel at the periods when it is most required in a light castings foundry. Two processes are used, the basic electric and the Tropenas converter. Stress is laid on standardized charging and working in the electric furnace, and a special technique employed in the cupola supplying iron for the converter. It is claimed that by the employment of these methods, loss of production caused by the pouring floor waiting for the furnace, or vice-versa, is eliminated. Appendices give details of the preparation of the linings, the properties of the steels made, and a note on fluidity.

Introduction

1. The methods outlined in this paper are employed in a foundry producing 95 to 100 tons of finished carbon steel castings weekly. Although this is a modest tonnage, it is just double the output for which the plant was originally designed. As the castings are almost entirely light and made in green sand, the floor space must be utilized to the utmost for the production of molds. A typical week's output was made up of over 5,000 castings totalling 97 tons. The average weight is 38 lb. with very occasional castings falling in the hundredweight (112 lb.) and upward class. This output can only be maintained by careful planning and working to a predetermined program. The planning is based on the number of molds which can be produced in a given time by the equipment in-

† Official Exchange paper of the Institute of British Foundrymen presented at the 46th Annual A.F.A. Convention at a Steel Session, April 24, 1942, Cleveland, O.

* Lake & Elliot, Ltd.

stalled. The core output is adjusted to suit this, the molds finished, cored up, and closed as made.

2. It is then necessary to have liquid steel available to pour the molds, in order that the floor may be cleared and the cycle repeated. This paper is a description of the steps taken to standardize steel production so that molds may be poured when ready.

3. Two processes are in use, the basic electric and the Tropenas or side blow converter. This combination has two great advantages:

(a) The basic electric furnace can use a wide range of scrap and produce a low-phosphorus, low-sulphur metal, the remelt from which can be used in conjunction with west coast hematite in the Tropenas to produce steel with a phosphorus and sulphur content comparable with electric steel.

(b) The electric furnace can be adjusted to produce a heat of steel at precise intervals (of 4 hr. in this case), day and night, while the Tropenas can produce heats at high speed during the peak casting period which in most foundries is during the afternoon.

4. As there are so few castings of large weight, it is not possible to open up the nozzle on a mold of several hundredweights* capacity and, if it were possible, it would be undesirable as the standard steel is at much too high a temperature for heavy castings.

5. Hand-shanking from both types of furnace is practiced to a great extent, small molds being poured in this manner without difficulty.

Table 1

TAPPING TIMES

Electric Furnace		*Converter*	
A	*B*		
2:00 a. m.		1:30 p. m. Soft	
6:00 a. m.		2:15 p. m. Hard	
	9:00 a. m.	2:45 p. m. Soft	
10:00 a. m.		3:15 p. m. Soft	
	1:00 p. m.	4:00 p. m. Hard	
2:00 p. m.		4:30 p. m. Soft	
6:00 p. m.	5:00 p. m.	5:15 p. m. Soft.	Delayed to permit 5:00 p. m. heat from B.
10:00 p. m.			

* The designation "hundredweight" used in this paper refers to the British hundredweight of 112 lb.

6. Table 1 shows the timetable which is worked in the foundry under consideration.

Table 2

PHASES OF OPERATION

	Electric Furnace *Description of plant*	*Tropenas Converter* *Description of plant*
1.	Charging and melting	Melting and desulphurizing
2.	Oxidizing (Converting and slagging off)	Blowing (Converting)
3.	Reducing (Refining) Finishing and tapping	Finishing and tapping

7. Each process is considered in three phases, as shown in Table 2.

Table 3

STANDARD TIME TABLE FOR PROCESSES

Electric Furnace	*Time*	*Converter*	*Time*
Previous tap complete	9:00	End of heating period	12:45
Fettling furnace complete	9:15	Fettling complete	12:57
Charging complete	9:45	Charging complete	1:00
Melting complete	11:45	Blowing complete	1:22
Slagging off complete	11:50	Finishing and recarburizing	1:25
Finishing complete	12:50	Ready to tap	1:28
Ready to tap	12:55	Tap complete	1:30
Tap complete	1:00		

8. Table 3 shows the standard timetable which is aimed at for both processes.

9. It is not proposed to deal in detail with the chemistry of the processes, as both are fairly well-known, but to describe the mechanism of standardized steel production.

Part I

BASIC ELECTRIC PRACTICE

10. The furnaces in use are of the electro metals type with two top electrodes and a conducting hearth. They are rectangular in shape with nut and screw operated tilting and elevating gear. The maximum capacity is 50 hundred-weight (2.8 tons) and charging is entirely by hand. The nominal rating is 650 k.v.a.

11. The basis of the process lies in standardization of the charges, a controlled boil and speed in working.

(a) *Charging and Melting*

12. The charge is made up of 45 to 47 hundred-weight (5040 to 5264 lb.) of mixed cold scrap of variable size and consisting of approximately 75 per cent scrap and 25 per cent steel turnings. The heavy scrap is charged first, directly under the electrodes, light scrap is charged around the electrodes and in the center of the furnace, and the steel turnings round the sides.

13. It is found that even slight variation from these proportions causes a considerable lengthening of the melting time; thus, an increase to 30 per cent for the turnings increases the time of a heat by 15 min.

14. The time taken to charge the scrap is between 20 and 30 min., according to the size. The heavier scrap takes longer than the medium variety, which can be readily handled by shovels.

15. The aim is to melt from the bottom upwards, the arc being concentrated on the heavy scrap to form a pool of metal quickly. By this means a constant arc is maintained. Lime is added with the charge, about 75 lb. to the ton being used. This quantity is varied according to the condition of the scrap, dirty or rusty scrap receiving more and high quality material rather less.

16. Melting is conducted as rapidly as possible with a load of 5,000 amp. at 80 to 85 volts. The time taken to melt a charge of 45 to 47 hundred-weight (5040 to 5264 lb.) from the cold is usually 2 hr. During the melting period care is taken to prevent excessive heat in the center of the furnace by frequently pushing the charge towards the center. This prevents over-oxidation or direct attack by the arc on the furnace bottom. Further lime is added from time to time to form slag.

17. When the bath is all clear-melted, the temperature should be just high enough to insure a liquid slag under normal conditions.

(b) *Oxidizing and Slagging Off*

18. The temperature is increased as additions of broken ore are made to remove the oxidizable elements. Properly worked, a bath condition arises when a critical temperature is reached and a violent boil takes place. It is essential that this boil be secured. A short and vigorous boil is preferred to a long slow boil, carbon being reduced from approximately, 0.38 to 0.09 per cent in 10 min.

19. This short vigorous boil on a rising temperature gradient

appears to be a crucial point in successful practice. Thus, if no boil takes place, the slag is glassy and reflects heat causing the roof to run and making the later formation of a true reducing slag very difficult. Also the absence of a boil appears to be associated with sluggishness in the finished steel.

20. A long slow boil at constant temperature leaves a bath which is very difficult to kill and which wastes a great deal of time during the finishing period. The essentials are to melt a bath with sufficient carbon (0.35 to 0.45 per cent) to cause a strong boil, to feed ore slowly and steadily while the temperature is raised and not to cause boiling at a low temperature by considerable stirring or rabbling.

21. Immediately the boil has died down and a test shows a soft bath, a sample is sent to the laboratory for phosphorus estimation. The first slag is now poured off and a fresh lime slag put on. Fairly strong oxidizing conditions are maintained until the laboratory report is favorable.

22. At this stage, carbon, silicon, manganese and phosphorus are reduced to a minimum and are present in approximately the following quantities: Carbon 0.09; silicon 0.008; manganese 0.10 and phosphorus 0.015 per cent. There is no reduction of sulphur during the period of melting and oxidizing.

23. The slag at this stage is quite black and inclined to brittleness after cooling, containing CaO, 40 per cent; FeO, 24 per cent; SiO_2, 17 per cent; MnO, 4 per cent; P_2O_5, 0.9 per cent; and Al_2O_3, remainder.

(c) *Reactions of Oxidation*

24. The chemical changes which take place during the 2 hr. period of melting and oxidation probably occur in three phases.

(1) *Elimination of silicon and manganese.* The silicon and manganese are oxidized by the presence of iron oxide added in the ore or included with the scale.

(2) *Elimination of phosphorus.* The elimination of phosphorus takes place secondary to the oxidation of silicon and manganese. Three definite conditions are necessary for the efficient removal of phosphorus: (1) excess oxygen, (2) very basic slag, and (3) low temperature.

(3) *Elimination of carbon.* Similar to silicon and manganese,

the elimination of carbon depends upon the amount of iron oxide included in the charge or added in the ore. It is standard practice to take the carbon down to the minimum in order subsequently to recarburize to the hardness desired.

(d) *Removal of the Oxidizing Slag*

25. After the elimination of the carbon, silicon, manganese and phosphorus, the bath is ready for the removal of the oxidizing slag. The removal is carefully supervised as the slag is carrying phosphorus, and, under the reducing conditions which follow, this would revert to the metal. Slagging is conducted as follows:

The furnace is slightly tilted and the slag poured or lightly raked off, the load is then taken off and the electrodes raised. A little lime is added to thicken the slag, which greatly facilitates the slagging operation, and care is taken to remove all traces of slag from the sides and banks of the bath.

26. Skimming is conducted as rapidly as possible in order that heat should not be lost during this period.

27. When the bath is in good condition, the complete removal of slag is accomplished in 7 or 8 min. To the slag-free bath is added 10 lb. per ton ferrosilicon to quiet the metal which aids in producing a more uniform recovery when recarburizing takes place for higher carbon steel.

(e) *Refining, Finishing, and Tapping*

28. In the case of low carbon steels, no carbon is added at this stage, but for higher carbon steels 20 lb. of anthracite duff is thrown into the bath, followed immediately by one half the total ferromanganese addition.

29. The bath is now ready to take the refining slag which consists of 50 lb. lime, 20 lb. fluorspar and 7 lb. coal dust. The load is again introduced and refining begins.

30. The total refining time is approximately 1 hr., half of which is taken in forming the slag and the rest in deoxidizing and acquiring heat.

31. Low power input of 3,500 amp. at 85 volts is used at first, when the slag is quite black in color, and after about 10 min. as the slag begins to melt, a small amount of ferrosilicon is added which helps to hasten deoxidation.

32. During this period, the consistency of the slag is carefully observed, not being allowed to become too viscous or too thin.

33. When the slag is too thick, contact with the metal is not made and sulphur elimination does not proceed efficiently. If it becomes too thin, serious softening of the roof and walls takes place.

34. The slag is worked up to strongly reducing conditions by the addition of lime and coal as required, and at this stage is white in color, with a strong smell of acetylene denoting the presence of calcium carbide. At this point, the power input is increased to 4,000 amp. Spoon samples are taken for general conditions of the steel and the metal quieted by small additions of ferrosilicon.

35. All samples during the refining period are taken with a cold spoon freed from metal and slag before use. The spoon is carefully warmed and slagged before dipping into the bath. Care is used to take the samples from the same position in the bath.

36. When the metal is hot enough and the slag in good condition, a sample is taken for carbon. Final adjustment is made with hematite and additions of 45 per cent ferrosilicon and 80 per cent ferromanganese are added to bring these elements to the desired quantity. The additions of ferrosilicon and ferromanganese are calculated from the known weight of metal in the bath.

37. The additions are allowed to melt and the bath well rabbled with a bar before a sample is poured into a sand mold. This sample should be quiet and piping. The load is then taken off and the metal allowed to stand 2 or 3 min. before tapping to enable the slag to separate.

38. The slag being highly basic and reducing conditions properly controlled, sulphur is efficiently reduced from 0.050 to 0.014 per cent.

39. Tapping takes place through a tap hole built up with sand outside the door. Although this is a somewhat lengthy procedure, it prevents the slag from running with the metal and avoids serious variation of carbon content and inclusions of non-metallic material.

40. The metal is tapped into bottom-pouring ladles which are preheated by gas burners to approximately 1472°F. (800°C.) and aluminum is added as the bottom of the ladle becomes well covered.

41. The tapping temperature for shanking steel is in the neighborhood of 3002°F. (1650°C.) and for direct-pour heats approxi-

mately 2876°F. (1580°C.) Details of pouring times and temperatures are given in Table 4. Unit consumption is at the rate of 869 per ton, inclusive of coke-load and preheating.

Table 4

POURING TIMES AND TEMPERATURES

	Shanking Heats,		*Bottom Pouring Heats,*	
Electric Furnace	°*F.*	°*C.*	°*F.*	°*C.*
Tapping temperature	3002	1650	2876	1580
Temperature—First Pour	2912	1600	2840	1560
Temperature—Last Pour	2840	1560	2786	1530
Time pouring (min.)		25		20
No. of molds		80		67
Weight of metal cast (hundredweight)		47		45

42. The temperature readings are taken with an optical pyrometer, looking on to a clean stream of metal, and a correction of 7 per cent added.

Part 2

TROPENAS CONVERTER PRACTICE

Description of Plant and Converter Lining

43. The equipment in use consists of one 20 hundredweight (2240 lb.) (nominal) Tropenas converter with a positive blower to furnish air. One balanced-blast cupola, 27 in. diameter capable of melting 3 tons of iron per hr. and one 2-ton capacity ladle for receiving the cupola iron for transfer to the converter; one lip pouring ladle from which steel is hand-shanked, and several bottom pouring ladles, all of which are preheated by gas burners.

44. The vessel is nominally of 1 ton capacity but the first charge is never less than 27 hundred-weight (3024 lb.) and this increases as the lining wears. The lining is 8-in. thick, except at the tuyeres side where it is 11-in. There are five 1⅛-in. diameter tuyeres formed in the rammed lining for which a proprietary material is used. It is essential to control the moisture content at 8 per cent during ramming and to take steps to secure adequate drying and preheating before the first charge. The average life of a lining is 70 blows.

45. The timetable is based upon a standardized converter charge, uniform vessel temperature and controlled blowing conditions. The tuyeres must be perfectly perpendicular to the axis of the vessel, an error of a degree or so prolonging the blow 5 to 8 min. and yielding cold steel.

(a) *Melting and Desulphurizing*

46. The cupola is fettled (cleaned) and patched each morning, this operation taking roughly 2 hr. The sand bottom is rammed-up and a fire started, which is allowed to burn through steadily without forced draft, and in about 2 hr. charging begins.

47. As small converters cannot easily be held to size, no patching of the vessel takes place and the capacity of the vessel increases during the week. Under these conditions, a standard cupola charge of constant weight cannot be maintained without seriously modifying the chemical composition of the iron charged to the vessel.

48. To avoid variation of chemical composition in the charge to the converter, the cupola charges are adjusted. Experience has shown that the converter weight increases along the following lines:

> At the beginning of the week, 27 hundred-weight (3024 lb.) are required, and, as little wear takes place during the first two days, three cupola charges of 9 hundred-weight (1008 lb.) to the blow suffice. After the second day the weight increases by 1 hundred-weight to 28 hundred-weight (3136 lb.) and four cupola charges of 7 hundred-weight (784 lb.) are used. For the fourth day, the converter weight will have increased to 30 hundred-weight (3360 lb.) and three units of 10 hundred-weight (1120 lb.) are used.

Table 5

CUPOLA CHARGE SHEET

	No. of cupola charges in converter charge	*Weight of cupola charge, hundred-weight*	*Total converter charge, hundred-weight*
Monday	3	9	27
Tuesday	3	9	27
Wednesday	4	7	28
Thursday	3	10	30
Friday	3	10	30
Saturday	4	8	32

49. Table 5 shows the cupola charge details for the full week. In this manner, a uniform composition is obtained without difficulty as the following figures for six blows testify:

Total Carbon	(per cent)	3.19	3.03	3.11	3.03	2.95	3.00
Silicon	(per cent)	1.41	1.41	1.41	1.35	1.41	1.13*

50. The charges consist of 70 per cent steel foundry scrap and

* Si reduced.

30 per cent hematite pig iron, the silicon being adjusted by the use of 45 per cent ferrosilicon to give a final silicon of 1.40 to 1.50 per cent.

51. The coke used is of the Welsh variety, coke to metal ratio being 1:10. Chalk containing 55.0 per cent CaO and having a moisture content of 1.96 per cent is used instead of limestone, 25 per cent chalk to coke by weight being used. Melting losses, despite the sandy nature of the scrap and pig, are constant at 5 per cent.

52. Charging takes place immediately the bed has been made up, and as the cupola is hand-charged, the steel is charged first and the pig charged round the sides. Charging is completed in 40 min. The tuyeres of the cupola are set at a height that enables the cupola operator to secure enough metal for the converter in two taps. The taps run at regular intervals of 15 min. with intervals of 5 or 6 min. between each converter charge, during which time the tuyeres are cleaned and the slag-hole made up. Hot iron is secured from the cupola, the temperature being 2660°F. (1460°C.) (optical pyrometer).

Desulphurization

53. Soda ash is used for desulphurization, one pound of sodium carbonate to one hundred-weight of metal being added to the receiving ladle before tapping. When the metal is tapped, a violent reaction occurs and heavy fumes are given off; after the second tap the reaction occurs again. Sulphur reductions as shown by recent analysis are as follows:

Cupola	S	(per cent)	0.071	0.080	0.068	0.078	0.067
Ladle	S	(per cent)	0.032	0.037	0.035	0.035	0.029

When the metal has come to rest, the ladle is removed from the cupola pit and the metal skimmed ready to be poured into the converter.

(b) *Blowing (Converting)*

54. After desulphurization, the weight of the metal is checked and poured into the converter which is in the charging position. The vessel is run up and the level adjusted by the operator. Blowing always takes place on the same angle. A quadrant is attached to the vessel clearly showing the angle, divisions of 5-10-15-20 degrees being shown by a pointer which revolves with the vessel. Blowing takes place on the 15 degree mark.

55. After the level is adjusted the blower is started and blast at 4 lb. per sq. in. pressure introduced. The operator records the time on a board and the blow is on.

56. A normal blow is as follows: As the blast strikes the bath, light yellow sparks and a small flame, going straight up the hood, proceed from the mouth of the converter. In about 5 min. a reddish brown flame appears directly over the tuyeres. This spreads and develops in length and marks the beginning of the ignition period. At this stage any ferrosilicon that may be considered necessary is added to the converter in lumps. Three minutes after ignition, the flame attains its full height and a vigorous boil ejects a little slag and metal from the mouth of the vessel. At this point the blast pressure is gently reduced to 3 lb. per sq. in. and the vessel "moved up into the wind."

57. It is not considered good practice to reduce the blast pressure rapidly, as sudden reduction results in the loss of the flame. By the time the boil occurs, the bulk of the silicon and manganese have been oxidized together with a small amount of iron, passing into the slag as silica, manganese oxide and iron oxide respectively. After reducing the blast, the flame remains steady, being "solid" and having length, until about 12 min. after ignition when the carbon flame ascends voluminously and intensely white in color. As the carbon becomes exhausted, the flame becomes streaked and diminishes in length. At this point the converter is turned down, the blow is completed.

58. The bath at the end of the blow is in a highly oxidized condition containing approximately carbon, 0.08 per cent; manganese, 0.005 per cent; and silicon, 0.008 per cent. No reduction of sulphur or phosphorus takes place, and actually a slight increase of these elements occurs, owing to the blowing loss which is roughly 8 per cent.

59. The practice of adding ferrosilicon to the converter is only used when metal is to be hand-shanked. It is found that additions of ferrosilicon have a pronounced effect upon the action of the flame, usually two or more boils taking place and, in the closing stages of the blow, it is not unusual for several false drops of the flame to take place before the carbon is finally exhausted. With such inconsistency of flame, the possibility of under or over blowing is considerable.

Finishing and Tapping

60. After the converter is turned down, deoxidation takes place by the addition of 45 per cent ferrosilicon and 80 per cent ferromanganese. The ferrosilicon at the rate of 12 lb. per ton or 25 per cent is added in tins, the slag being pushed away from the metal and the tins thrust into the bath. The ferromanganese addition is made by dipping the lumps in water and throwing them with force through the mouth of the converter, relying on the wet manganese to explode the covering of slag and penetrate into the metal. The loss of manganese is approximately 20 per cent, 1.20 per cent being added to finish at 1.0 per cent. The metal is then well rabbled with a bar to work in any manganese that may have been trapped by the slag.

61. The carbon is adjusted, when necessary, by the use of cupola metal. This method of recarburizing is easily adaptable, quick and efficient, hot hand-shanks of pre-determined capacity being used. The actual time taken to recarburize a heat is 3 min. After recarburization, the vessel is turned up to within a few degrees of the blowing position (to obtain the maximum movement of the metal) and back again to the pouring position, then rabbled well with a bar to insure homogeneity. The ladle is brought into the pit and the slag is held back to insure that the aluminum, which is added to the ladle, will be taken up by the metal, after which the slag is allowed to run freely.

62. The tapping temperature of converter metal compares favorably with electric furnace metal. Shanking-heats are tapped at 3020°F. (1660°C.) and bottom pouring heats at 2912°F. (1600°C.)

63. Table 6 gives details of pouring temperatures and times.

Table 6

CONVERTER POURING TEMPERATURES AND TIMES

Tropenas Converter	*Shanking heats*		*Bottom pouring heats*	
	°F.	°C.	°F.	°C.
Tapping temperature	3020	1660	2912	1600
Temperature—first pour	2966	1630	2840	1560
Temperature—last pour	2867	1575	2786	1530
Time pouring (min.)		25		20
No. of molds		88		75
Weight of metal cast (hundredweight)		32		30

ACKNOWLEDGMENT

64. The authors wish to thank the directors of Lake & Elliot Ltd., for permission to publish this paper.

Appendices

1. LINING AND PREHEATING OF ELECTRIC FURNACE

Lining: The side walls and arches of silica bricks are built into position. The bottom is then made up as follows:

Ground magnesite to the thickness of 1-in. is spread over the bottom next to the shell, over which is laid one course of 3-in. magnesite brick, a further 1-in. of ground magnesite spread over the bricks followed by 1-in. of fine, dry dolomite.

The actual melting hearth consists of dolomite bonded with tar, rammed into place with pneumatic rammers.

The tar is de-hydrated (0.5 per cent max. H_2O) and 8 per cent by weight of tar to dolomite is used. The tar and dolomite are preheated before mixing but are rammed into the bath cold.

The roof is built with silica bricks.

Preheating: Coke is charged into the furnace and a load of 2000 to 2500 amp. at 80 volts maintained. About 72 hr. heating is necessary to bring the bottom or neutral current into operation in a new furnace.

Preliminary heating prior to the week's campaign is similar to the above with the heating time reduced to 6 hr.

2. RAMMING, DRYING AND PREHEATING CONVERTER VESSELS

The bottom of the converter vessel is made up of three courses of 3-in. silica bricks. A well-known proprietary material is used for the walls, which are rammed round a wooden former, 27-in. across by 51-in. high, sectional in construction to facilitate removal.

The vitrified and burned material is chipped off the face, leaving about 1½ to 3-in. old material round the shell. This is slurried down and the new material rammed into place with pneumatic rammers. The vessel is allowed to stand, drying naturally for as long as possible before being put into work.

Drying and heating are conducted as follows: A small coke fire is started and allowed to burn slowly for 15 hr., additions of coke being made as required. After 15 hr., approximately 5 hundred-weight (560 lb.) of coke is added and air blown in through the tuyeres at 1½ lb. per sq. in. pressure. After blowing once up and down, a further 2 hundred-weight (224 lb.) of coke is added and the blowing repeated. Blowing up and down is maintained for 30 min. in each operation; the vessel is then allowed to hang nose downwards with the tuyere box open.

The daily practice is similar. After the nose has been made up, a

fire is started at 8:00 a. m. and alternate blowing up and down the hood takes place at 30 min. intervals. The vessel is then turned down until the coke is withdrawn. Coke consumption increases as the size of the vessel increases and reaches a maximum of 10 hundred-weight (1120 lb.)

3. PHYSICAL PROPERTIES

Table 7 details the chemical composition and physical properties of the steels after normalizing from 1652 to 1688°F. (900 to 920°C.)

Table 7

CHEMICAL AND PHYSICAL PROPERTIES OF CONVERTER STEEL

Composition—per cent					*Physical Properties*				*Heat No.*
C	*Si*	*Mn*	*S*	*P*	*Yield point lb. per sq. in.*	*Ultimate strength lb. per sq. in.*	*Elong., %*	*Reduction of area %*	
Basic Electric Furnace									
0.20	0.25	0.85	0.020	0.015	46,592	73,360	39.0	40.0	C.10970
0.41	0.33	1.10	0.020	0.015	55,440	93,100	25.0	45.0	B.3448
Tropenas Converter									
0.18	0.22	0.85	0.032	0.037	38,430	71,680	36.0	56.0	F.9261
0.33	0.35	1.10	0.032	0.037	48,800	79,630	24.0	30.0	F.8342

4. FLUIDITY

The question of the relative fluidity of converter and basic electric steel is often discussed. It is usually held that converter steel is more fluid than basic electric steel.

In the experience of the authors, temperature is by far the strongest factor in fluidity. Temperature readings over a considerable period have shown that converter steel is consistently 104 to 140°F. (40 to 60°C.) hotter than electric steel. It is their opinion that with well-made steels the difference in fluidity of the two types of steel at the same temperature is very small.

Non-fluid steels are occasionally encountered and, in the case of electric steel, this is usually found to occur in heats on which the boil has been unsatisfactory. This is often followed by a prolonged period under the final reducing slag. The steel is frequently found to be high in silicon and to contain considerable inclusions.

In no discussion on fluidity has any reference been found to non-fluid converter steel. Yet this occasionally occurs. It appears to be associated with cold iron in the converter charge and an extended period before the boil begins. A very fluid and sloppy slag high in FeO is formed and it appears that this results in a high proportion of non-metallic inclusions. It would be interesting to know if there is any definite evidence that lack of fluidity is associated with the presence of inclusions.

Production of Copper Patterns by Electro-Forming

By A. K. Laukel*, Detroit, Mich.

Abstract

The history of electro-forming is reviewed, showing where the process was first employed for production of patterns. The author then discusses corrosion aspects of metals used. The processing of copper patterns is described, giving plaster mixture employed. The expansion and contraction features of pattern materials are discussed, and the method of making molds for electro-plating is detailed, with special reference to making odd designs. Limitations and advantages of the method are compared. The author also takes up other points in making patterns by this method.

Historical

1. Historically, the earliest work on electro-forming dates back to 1840. At that time the first patent, No. 8610, was issued by the English Patent Office for a process of manufacturing of embossing and printing plates used in dyeing of calico. This was the beginning of the present day electrotypes and rotogravure plates with which we are all familiar. Rebuilding worn parts of machinery by deposition also has its origin from this patent.

2. The first mention of producing patterns by electro depositions was made in 1841 by Thomas Spencer, British Patent No. 8865. He stated that it could be done, but did not go into detail. The only electricity available during those times was made from wet cells, and naturally they were limited in the scope of work turned out.

3. The first work in this country, on record, on deposited patterns was done by Keep, of the old Michigan Stove Company in

* President, Electro-Chemical Pattern & Mfg. Co.

Note: This paper was presented at a Patternmaking Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 20, 1942.

1890. He had the idea of reproducing the fancy designs that were so prevalent on stoves at that time. To what extent and how long the process was used the records do not reveal.

4. In 1906, Antisell mentioned* a method of producing patterns as well as copper matches by electro deposition. Nothing much was done to further the production of patterns by this method until we started in 1923. No doubt, work had been done but no published records seem to be available. On all the published works on patterns up to this time, no mention had been made as to the accuracies held. This was our main objective when work was started on the process.

5. To date, in addition to commercially used patterns there are several articles made by electro-forming. On all these processes, certain molding materials that are most suitable have to be used. In general the most common are wax, bismuth, lead alloys and plaster of paris.

CORROSION ASPECTS

6. Curiously enough, as far back as 1805, when two dissimilar metals such as zinc and tin and zinc and iron were brought together in a water or salt solution, the reason and the results were known. The zinc went into solution at the expense of tin and iron, and with aluminum unknown at that time, the aluminum would disintegrate at the expense of the tin and iron, and, to a lesser degree, with zinc. Yet we still have claims that aluminum solder whose base is zinc and tin is a satisfactory solder for aluminum under all conditions. This can be checked from data of the *"Electro-motive Series of Metals."* Studying these series indicates that there will never be developed a satisfactory soft solder for both aluminum and magnesium. Along the same lines we wonder sometimes why excessive corrosion takes place in dowel and screw holes of patterns; also, at the parting surfaces of the pattern when fastened to plates and even on plate surfaces coming in contact with plated patterns. Some of this corrosion can be overcome by selecting the right metals or combination of metals wherever practical.

7. Magnesium plates and patterns have come to the front in the last few years. No doubt magnesium will be continued to be used due to its ease of machining and lightness. One of the diffi-

* Antisell, F. L., *"Electricity in the Foundry,"* TRANSACTIONS, AMERICAN FOUNDRYMEN'S ASSOCIATION, vol. 15 (1906), pp. 87-88.

culties in using magnesium is its ease of corrosion. Little can be done to overcome this plate corrosion when plating iron, copper, or brass patterns on magnesium plates. Excessive corrosion takes place at the juncture of plate and pattern. Magnesium and aluminum patterns on the other hand can be plated on either aluminum or magnesium plates with very little effect.

8. Some of the dowel and screw hole corrosion can be overcome in aluminum and magnesium patterns if zinc plated iron dowels and screws are used. It might be suggested to zinc- or chromium-plate the parting surface of iron, copper or brass patterns. This will eliminate to some extent the corrosion that takes place when aluminum and magnesium are used for plates. Copper plated dowel pins which are being used by some companies is one step forward in this direction especially when used for doweling iron patterns. This procedure eliminates to a great extent the rusting in of dowels.

COPPER PATTERN PRODUCTION

9. For copper pattern production, plaster of Paris was formally adopted and 99 per cent of our patterns are made by using plaster as a molding material. Wax and soft alloys can only be used for special cases. When wax is used the object to be reproduced is pressed into the molding material. This eliminates the use of wood masters, especially where wax is used for fillet and glued sections that might be easily torn loose from the pattern. Many times wood patterns are patched with plaster, paper and plastics. White metal has its limitations due to the fact that it cannot be poured on wood patterns and even on some metal masters where solder is used in joining sections or producing fillets.

Plaster Mixture

10. In our case, as well as in general pattern making, a good grade of dental plaster should be used. The general accepted practice in pattern making is to sift the plaster into water until no more is taken up. It is anyone's guess to determine the necessary amount. The resulting set plaster varies in hardness, strength and expansion. The most consistent results are obtained by measuring the water and weighing the plaster. Three pounds of the average plaster is used to 1 qt. of water. The water is measured and the necessary amount of plaster is added. Allowed to stand for a few minutes, it is stirred until the original consistency thickens,

and then poured. For thinner consistency, less plaster can be used, as low as 2½ lb. to 1 qt. of water. Plaster should never be poured until the original consistency thickens, otherwise, the time of setting is increased, softer plaster is produced and a tendency to stick results. Plaster mixed with 3 lb. to 1 qt., setting time about twenty min., expands .0022-in. per ft. when still hot, then drops down to .0019-in. per ft. when cool, and does not change after standing for months. This expansion can be cut to some extent by adding inert materials, increasing the water content and by the use of accelerating and retarding mixtures. There are plaster mixtures on the market that set to a very hard dense mass which are used a great deal for master patterns on duplicating machines.

Expansion and Contraction

11. Working with some of these mixtures, very interesting results were obtained, especially with their expansion and contraction properties. Using 1 qt. of water to 6 lb. of plaster, one of the mixes specified by the company, an expansion of .0015-in. per ft. was obtained when hot. Two days later when dried, .0012-in. per ft. was registered, 10 days later, .002-in. per ft., and one month later a shrinkage of .003-in. per ft. occurred. It is even possible to get shrinkage with these materials after drying a day or two by increasing the water content. Although these materials may serve their purpose for lack of a better one, the results show that they are very unstable in the set form.

12. A convenient way of measuring expansion is to take a standard steel ft. scale, grease and lay it on a flat plate, then put a small piece of brass on each end of scale, using grease on bottom to hold in position. Pour plaster 1-in. or more on top of scale and brass, when set remove scale and let scale cool down to room temperature. Then, with the aid of feelers and scale, the exact expansion can be determined. There are other methods that can be used, but this is the most convenient.

13. Expansion causes the difficulties that sometimes occur in removing patterns from plasters and plaster cores from core boxes. Expansion does not reach its maximum until the plaster temperature is at its greatest. Any tendency to stop expansion will cause a warping.

SEPARATORS TO AID DRAWING PLASTER FROM PATTERNS

14. For separators or materials to aid drawing of plaster from

patterns or cores boxes, there are many that are advocated. We use the ordinary thin grease or dope, especially those that contain soap materials and oil. The soap in the grease not only acts as a separator, but allows the plaster to wet the surface of the pattern to some extent, thereby getting more accurate detail and less bubbles. Only a skin coating is necessary to facilitate removal and to prevent sticking.

MAKING MOLDS

15. In making molds for electroplating, we use the procedure as mentioned. Most of the expansion that takes place in the plaster dissipates by the time the pattern is finished. The single shrink patterns that we work from are either wood or metal. These patterns should be split, but if necessary, we can take a solid pattern and make a split duplicate copper pattern from it. This is the only process by which the working pattern can be made first. Trial castings taken from it and any changes necessary can be done before production patterns are started. This is possible because there is absolutely no shrinkage between the copper pattern and the pattern to be duplicated.

16. The required number of molds to fill a plate are taken from the pattern submitted. These molds are dried in an oven at temperatures below the decomposition point of plaster, which is around 140°F. The dryness of the plaster can be determined by loss of weight, usually 35 per cent, or by noting when the conductivity becomes zero. There is an instrument developed for this purpose, known as a moisture detector. The molds are then waxed, allowed to cool and made conductive by suitable means, such as graphite or metal powders. Wires are attached connecting conductive surfaces and cathode rod in plating tank.

17. The plating is done in still tanks and allowed to plate until the desired thickness is obtained, usually from 3 to 6 days. Temperature of tanks is around 80°F. Minimum thickness of 1/32-in. is usually obtained, but in order to obtain this minimum, other parts of the deposit might be 1/8-in. or more in thickness. When deposits are finished they are removed from molds, hot tinned, backed up with white metal, and brass strips added in pattern. This brass acts as a good medium for screws and dowels and also for a strengthening agent.

18. These patterns are machined in a lathe to their parting

surfaces by placing them in plaster of Paris or white metal jigs. These jigs are made from the original patterns or copper duplicates. The machined halves are then matched cope against drag by the use of a plaster jig that has been made from the matched original pattern. The halves are tacked together with solder. Fins set up by machining are removed by filing. The patterns from this point are complete ready for mounting.

19. One proof that these patterns are accurate is that all copper patterns are machined and matched from the same plaster or white metal jigs. We hold accuracies to a few thousandths of an inch in machining. The copper surface contours made by the original pattern impression are absolutely perfect. Naturally, having patterns as alike as it is humanly possible to make them, castings are bound to be more regular and therefore, a good deal of the machining difficulties will be eliminated. The casting will naturally have a more uniform weight.

Odd Designs

20. Very frequently patterns with an odd design are required. These designs are not always machinable, and must be hand worked. With a number of patterns on a plate, this means either considerable working to templates, or slipshod guesswork as to shape, perhaps resulting in no two being alike. Quite often this odd design is the only means of holding castings in chucks or jigs for machining. If the patterns are alike, all castings fit the fixtures properly; if patterns are dissimilar, castings are often machined "off center." Copper patterns eliminate the need of unsightly serial numbers.

21. Engineering changes can be readily made on copper patterns. They are very easily altered or patched with brass, copper or steel, and a soldering iron, without excess electrolytic corrosion between patch and pattern, as is readily noted on aluminum.

Limitations as to Size

22. We are limited to around 20-in. in the size of patterns we make. We also admit that we can not make patterns as light as aluminum. They do compare in weight with brass and iron. The wearing qualities compare favorably with cast iron and, in some cases, better. Try patching some of your iron or aluminum patterns with copper and note the difference in wear.

BACKING METALS

23. As has been stated, white metal is used to back these patterns. This alloy is one of the hardest that can be made and still serve the purpose. Also, its shrinkage has been cut down to around .005-in. per ft. It is composed of copper, lead, tin and about 20 per cent antimony. It is a misnomer to state that the average white metal, such as tin and zinc, is non-shrink, because it does shrink to a considerable extent. The only two common metals that will eliminate or reduce shrinkage are antimony and bismuth. These, when alloyed with tin, cadmium or lead, control shrinkage. Antimony having the ability to produce harder alloys and being cheaper was naturally chosen for a backing material.

ADVANTAGES

24. There are many advantages available in pattern making if one wishes to apply the principles of electro-forming to that art. In the case of aluminum or magnesium core boxes used on core blowing machines, many of these are brass faced. These facings become worn or uneven and must be replaced or spotted. Depositing copper on worn faces and re-machining eliminates replacement and spotting. Many rapidly wearing sections of boxes can be replaced by electro-formed reproductions.

25. In case the pattern or core box is made from brass or copper, worn spots can be rebuilt by deposition. Solder fillets can be replaced by copper. Many times, by patching up an old metal or wood pattern with wood, plaster, paper, etc., the desired changes can be made. The patched pattern can be used to produce the required number of copper patterns. Then the patches can be removed allowing it to be returned to its original state.

26. Due to the flexibility of the process, it oftentimes becomes very convenient to convert irregular parting jobs to cope and drag plates, especially where pattern and partings have complicated shapes, entailing an enormous amount of time of machining and the registering of cope and drag sections. An example of this is in the making of hand wheels, and ball and socket discs for valves, etc.

VERTICAL SHRINKAGE

27. In nearly all castings the vertical shrinkage as a rule is greater than the horizontal, or parting shrinkage. This can be

taken care of by making the pattern proper larger through the vertical dimension and keeping the parting dimension to size.

SEPARATORS

28. In case patterns are mounted on two sides of a plate, the working pattern is machined to size on body as well as core prints. A separator is placed between halves of pattern. This separator must have the thickness equivalent to the added rise wanted on cope. The prints are re-machined, making sure that only the cope side of prints are touched. The separator can be left on cope side of pattern or removed. In either case, we can produce our copper patterns, knowing the additional thickness. In case patterns are mounted on one side of the plate, the right thickness of separator will be used, but half will be on the cope side and half on the drag side of pattern.

CORES

29. Many times, in setting cores that have round prints, several difficulties can be eliminated if the core prints are made oval; that is, to size on the vertical dimension and a few thousandths over size on the parting dimension. This procedure tends to eliminate core crushes due to rapid setting of cores, misalignment of patterns and loose flasks. Core boxes can be used longer before crushes occur on parting of mold due to wear on box prints.

30. In construction, the pattern proper is brought to size first, then a separator is placed between the halves and prints machined. The vertical dimension is machined over-size, equivalent to the thickness of the separator. When the separator is removed, the vertical dimension corresponds to that of core box. Naturally, pattern costs will run considerably higher if one wishes to apply this system in machining the required number to fill a plate. In making copper patterns only one split, wood or metal, working pattern with this added feature is necessary to gain the effect.

NO CURE-ALL

31. In summary, we do not claim that deposited patterns are a cure for all pattern and casting ills, but they are one step forward in this direction.

DISCUSSION

Presiding: FRANK C. CECH, Cleveland Trade School, Cleveland, O.

Co-Chairman: V. J. SEDLON, Master Pattern Co., Cleveland, O.

MEMBER: How does a copper pattern compare in price with a pressure-cast plate?

MR. LAUKEL: In most cases, the cost of a plate of copper patterns will be higher, but there is no comparison between the accuracy of a cast plate and copper patterns. Then too, a double shrink pattern must be used in the case of a cast plate, whereas a single shrink or working pattern is used for duplication into copper patterns.

MEMBER: Does a pattern have to have shrinkage in it?

MR. LAUKEL: Copper patterns are made from the single shrink, or working pattern, either in wood or metal. There is absolutely no shrinkage in the production of copper patterns.

MEMBER: Must the patterns all be split?

MR. LAUKEL: We can only produce split patterns and cope and drag plates that can be mounted on plates.

MEMBER: How is the copper laid on?

MR. LAUKEL: It is done by electro-plating. The cavity made by the pattern is made conductive and plated until the desired shell thickness is obtained.

MEMBER: Would it follow the line of the box that is worn?

MR. LAUKEL: Core boxes that are worn on the parting surfaces can be brought to the original size readily by depositing an excess of copper and re-machining. Only boxes that are made of brass or copper, or those which are brass faced are adaptable to this process. For example, an aluminum or magnesium core box brass faced can be consistently rebuilt.

MEMBER: One firm has a special small core box made up for the purpose of replacing these cores. The cores are taken from this special core box, placed back in the worn box, and the copper is deposited, giving an exact duplication of the original.

MR. LAUKEL: The box was originally made about four or six years ago. We have rebuilt the surfaces on it about six times now. There are many places where it can be used. For example, there are intricate sections in a core box. In using an aluminum box which necessitates the insertion of an intricate section, a copper insert may be made of the section and placed in the box. When worn, it can be replaced with a duplicate copper insert.

MEMBER: Are there any limits as to the size of the patterns?

MR. LAUKEL: Yes, there are. Our limit is a pattern about 20-in. long. We cannot make the patterns as light as aluminum, but we can back them out to get them similar to brass and iron in weight, and they can be stacked up against iron as far as wearing qualities are concerned.

It is possible to take an old wood job, patch it up to suit a new design and take the required number of coppers from it. Then the wood pattern can be restored to its original design. The same is true with a metal pattern which can be exchanged for wood, wax or any other mate-

rial, and we can reproduce from it. The process is very flexible, and we can do a good many things which cannot be done in ordinary patternmaking. So far as patching and soldering are concerned, it is easy. Copper is a little more difficult to solder than brass, but it can be done with a hotter iron.

MEMBER: Have you any schedule of the approximate price of the plates? Does it run according to weight or size?

MR. LAUKEL: We do not have a definite price scale. With ordinary patterns we cannot give a definite figure unless we actually see the job and the type of work to be done.

MEMBER: If a new copper facing was built up on an aluminum core box, would the copper resist wear any more than the aluminum?

MR. LAUKEL: Yes. We cannot put the copper facing directly on aluminum. The box would have to be brass faced first.

MEMBER: Would the wearing qualities be improved by depositing chromium on the copper?

MR. LAUKEL: Wearing qualities would be definitely improved. One company has chrome plated heavy run copper fitting patterns to increase their life. Dull chrome is usually used.

MEMBER: Do you license this process?

MR. LAUKEL: We have not up to the present time.

CHAIRMAN CECH: In summarizing this whole discussion, would you say that the work which you are doing pertains to work of fine detail?

MR. LAUKEL: This process pertains to all split patterns, cope and drag plates, core sections, etc. where accuracy and uniformity of the finished casting is of prime importance. The cost of these patterns is very much less in comparison to machined brass, aluminum, or iron patterns.

J. F. CHAMBERS[1]: One of the drawbacks to plasters is that they have not been absolutely uniform as far as the setting time is concerned.

A special casting plaster has been developed that is claimed to set stabilized or to have a constant setting time. With this material, the foundryman or patternmaker can depend upon having plaster that is uniform in setting time, without having any soluble salts in it. It has been possible to produce set stabilized plaster by the addition of soluble salts but this new plaster is said to eliminate that necessity.

Another feature, advantageous in some kinds of casting plaster, is the expansion. The expansion rate of this new set stabilized plaster is said to be uniform. In certain cases, foundrymen like to have a plaster that has absolutely no expansion. Such a plaster has been developed.

MR. LAUKEL: It is the common practice in the average pattern shop to use guesswork in the mixing of the plaster of Paris, that is, sifting plaster into the water until no more is taken. With that set-up, it is not possible to get two plasters alike. If the plaster is weighed and the water is measured, a uniform mix can be secured every time. Usually, the plaster is not stirred long enough, causing it to stick to the mold or break up. If it is stirred until the consistency thickens and then poured out, better results are obtained.

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1 National Gypsum Co., Luckey, O.

The best separator for pulling plaster off patterns is a grease that contains calcium soap. It is possible to get much better detail and better release because the plaster has a tendency to wet the soap in the grease. The plaster lays to the job much better and the grease allows it to slip out. If an oil mixture is used without a soap being present, it will result in very poor reproduction of the pattern because the grease keeps the plaster away from the job and produces many bubbles. All plaster expands from 0.015-in. to 0.020-in. per ft.

Machinable 1.5 Per Cent and 2.0 Per Cent Chromium Cast Irons to Resist Deterioration at High Temperatures

By C. O. Burgess*, and A. E. Shrubsall*, Niagara Falls, N. Y.

Abstract

This paper describes a method of improving 1.5 and 2.0 per cent chromium cast irons and bringing them within the machinable range through ladle additions of alloys of the silicon-manganese-zirconium type. The experimental work shows that such chromium-bearing irons possess a high order of resistance to deterioration on long exposure at high temperatures [specifically 516 hours at 1472°F. (800°C.)], and that their resistance to oxidation and growth is not adversely affected by graphitizing ladle additions. The paper includes a general study of the phenomena responsible for the deterioration of cast iron at high temperatures. Cast irons containing nil to 2.0 per cent chromium are covered in this study and their oxidation, growth, and change in strength on prolonged exposure to 1472°F. determined. The development and penetration of a metal-oxide constituent into the cast irons is found to be intimately associated with high temperature deterioration. The improvement effected by chromium additions appears mainly to result from the ability of small amounts of chromium to inhibit and finally prevent penetration of this metal-oxide constituent.

Introduction

1. The present study had two main objects. The first object was to determine whether 1.5 and 2.0 per cent chromium cast irons of otherwise normal analysis could be rendered machinable, without the loss of their other highly desirable properties, through the use of recently developed special graphitizing alloys of the silicon-manganese-zirconium type, analyses of which are given in Table 2. The

* Union Carbide & Carbon Research Labs., Inc.

Note: This paper was presented at a Gray Iron Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 23, 1942.

Table 1

ANALYSIS OF TEST IRONS

Specimen No.	*Heat No.*	*Addition*	*Total Carbon, per cent*	*Combined Carbon, per cent*	*Silicon, per cent*	*Manganese, per cent*	*Chromium, per cent*	*Sulphur, per cent*	*Phosphorus, per cent*
1	8193	FeCr (0.5 per cent Cr)	3.15	0.64	2.76	0.53	0.47		
2	8757	FeCr (1.5 per cent Cr)	3.38	1.14	2.31	0.55	1.51		
3	8758	FeCr (2.0 per cent Cr)	3.33	2.25	2.19	0.57	1.96		
4	8759	FeCr (1.5 per cent Cr) + Alloy 1 (0.5 per cent Si)	3.29	0.90	2.35	0.61	1.51		
5	8760	FeCr (2.0 per cent Cr) + Alloy 1 (1.0 per cent Si)	3.35	1.05	2.40	0.63	2.02		
6	8761	FeCr (1.0 per cent Cr) + Alloy 3 (0.5 per cent Cr)	3.13	1.00	2.40	0.70	1.45		
7	8762	FeCr (1.0 per cent Cr) + Alloy 3 (1.0 per cent Cr)	3.01	1.44	2.21	0.83	1.84		
8	8763	Mn FeCr (1.5 per cent Cr)	3.27	1.37	2.48	0.81	1.54		
9	8764	Mn FeCr (2.0 per cent Cr)	3.27	2.02	2.44	0.90	1.99		
10	8765	FeCr (1.0 per cent Cr) + Alloy 3 (0.5 per cent Cr*)	3.25	0.97	2.69	0.71	1.48		
11	8766	FeCr (1.0 per cent Cr) + Alloy 3 (1.0 per cent Cr*)	3.22	1.54	2.51	0.83	1.93		
12	8835	FeCr (1.0 per cent Cr)	3.21	1.36	2.20	0.54	0.99		
13	8836	FeCr (1.0 per cent Cr) + Alloy 2 (0.5 per cent Si)	3.21	1.05	2.18	0.60	1.00		
14	8925	Base Iron	3.18	0.60	2.17	0.55	0.06	0.056	0.160
15	A-3	Alloy 3 (0.50 per cent Cr)	3.29	0.66	2.24	0.59	0.49	0.126	0.370
16	B-4	Low-carbon iron + Alloy 1 (0.9 per cent Si)	2.38	0.71	1.91	0.35	0.01		

* Small amount of iron ore added with graphitizer.

desirability of such irons was indicated by previous work[1] in which it was found that when the chromium content reached 1.0 per cent to 2.0 per cent, a definite increase in oxidation resistance (and presumably in growth resistance of cast iron) took place.

2. The second object of the investigation was to further study the phenomena responsible for the deterioration and growth of cast iron at elevated temperatures. In this study a series of irons containing nil to 2.0 per cent chromium was employed. A definite part of the investigation was to determine whether graphitization of normally white irons containing 1.5 and 2.0 per cent chromium would adversely affect their resistance to deterioration and growth at high temperatures.

TEST MATERIALS

3. The cast irons employed in the investigation are listed in Table 1. It will be observed from this table, that in addition to ten heats (Specimens 2 through 11) in the range of 1.5 to 2.0 per cent chromium, four lower chromium heats (Specimens 1, 12, 13, and 15), and two unalloyed cast irons of normal and low carbon content (Specimens 14 and 16) are included.

4. The heats in Table 1 are further classified as ungraphitized or graphitized. They are considered as graphitized if they received additions of alloys 1, 2 or 3. The analyses of the ferrochromiums and graphitizing alloys used in the preparation of the above heats are given in Table 2.

Table 2

ANALYSIS OF ADDITION ALLOYS

Alloy	*Chromium, per cent*	*Silicon, per cent*	*Manganese, per cent*	*Zirconium, per cent*	*Carbon, per cent*
1	....	75.65	7.08	7.23	....
2	....	62.25	5.92	6.07	....
3	30.05	36.97	7.73	5.72	0.28
FeCr	64.01	8.30	....	....	5.46
Mn-FeCr	59.36	4.64	10.51	....	4.14

USE OF ALLOYS 1, 2 AND 3 ADDITIONS IN PRODUCTION OF MACHINABLE 1.5 AND 2.0 PER CENT CHROMIUM CAST IRONS

5. In regard to the first object of the investigation, *i.e.*, the improvement of 1.5 per cent and 2.0 per cent chromium irons, it was

[1] Superior numbers refer to bibliography at end of paper.

Table 3

PROPERTIES OF 1.5 AND 2.0 PER CENT CHROMIUM IRONS UNTREATED AND TREATED WITH SPECIAL LADLE ADDITIONS

Specimen No.	*Heat No.*	*Addition*	*Chromium, per cent*	*Transverse Prop.*		*Tensile Strength, lb. per sq. in.*	*Brinell Hardness, No.*	*Chill Depth, in.*	*Machinability, 295 r. p. m.*
				Strength, lb.	*Deflect., in.*				
2	8757	FeCr	1.51	1910	0.161	38,000	332	Full-chill (2.00″)	Failed
4	8759	FeCr + Alloy 1	1.51	2140	0.246	44,750	286	0.63	Satisfactory
6	8761	FeCr + Alloy 3	1.45	2140	0.226	46,500	302	0.69	Satisfactory
									153 r. p. m.
3	8758	FeCr	1.96	1730	0.133	30,000	512	Full-chill (2.00″)	Failed
5	8760	FeCr + Alloy 1	2.02	1670	0.161	47,100	321	0.88	Satisfactory
7	8762	FeCr + Alloy 3	1.84	1790	0.142	45,900	387	1.13	Fair

The appearance of the chill blocks from the above six typical heats is shown in Fig. 1.

found that ladle treatment of such irons with the alloy 1 and alloy 3 rendered them machinable at moderate speeds and materially improved their physical properties and resistance to chilling. This is clearly brought out if representative untreated and treated irons of similar chromium content listed in Table 1 are compared. This comparison is shown in Table 3.

6. Machined surfaces of transverse bars of the six irons are shown in Fig. 2. The high speed steel tool failed after 1¾ cuts on the straight 1.5 per cent chromium cast iron (Specimen 2), while no visible tool wear was produced after two cuts on the 1.5 per cent chromium irons treated with alloy 1 and alloy 3 (Specimens 4 and 6). Similarly the tool failed immediately on the straight 2.0 per cent chromium iron, while no visible wear was shown after two cuts on the 2.0 per cent chromium alloy 1 treated iron (Specimen 5).

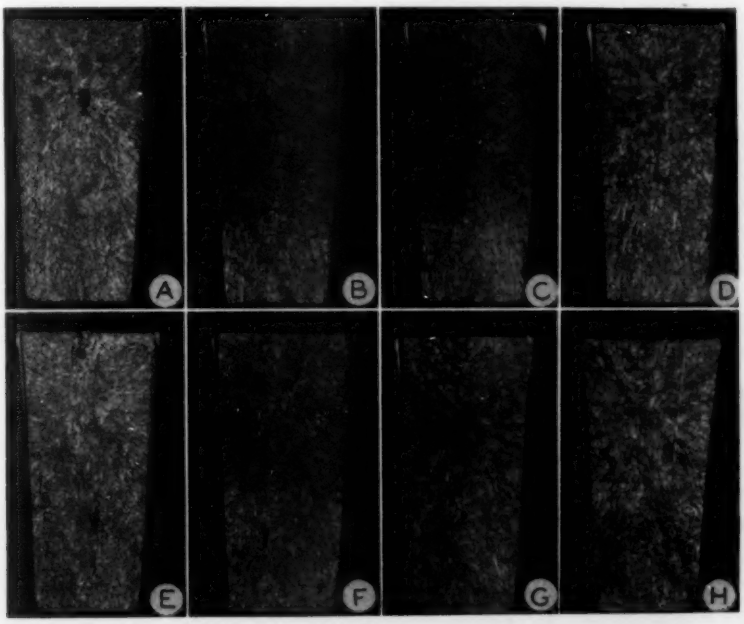

FIG. 1—EFFECT OF LADLE ADDITION ALLOYS ON CHILLING OF 1.5 PER CENT AND 2.0 PER CENT CHROMIUM CAST IRON. (A) SPECIMEN 2, 1.51 PER CENT CHROMIUM, NO TREATMENT; (B) SPECIMEN 4, 1.51 PER CENT CHROMIUM, ALLOY 1 TREATED; (C) SPECIMEN 6, 1.45 PER CENT CHROMIUM, 0.5 PER CENT CHROMIUM AS ALLOY 3; (D) SPECIMEN 8, 1.54 PER CENT CHROMIUM, NO TREATMENT; (E) SPECIMEN 3, 1.96 PER CENT CHROMIUM, NO TREATMENT; (F) SPECIMEN 5, 2.02 PER CENT CHROMIUM, ALLOY 1 TREATED; (G) SPECIMEN 7, 1.84 PER CENT CHROMIUM, 1.0 PER CENT CHROMIUM AS ALLOY 3; (H) SPECIMEN 9, 1.99 PER CENT CHROMIUM, NO TREATMENT.

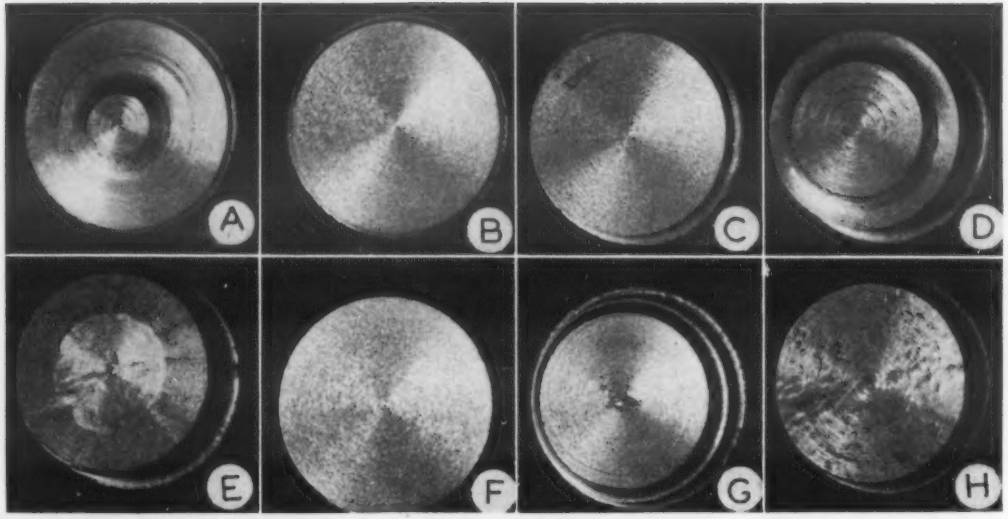

FIG. 2—APPEARANCE OF MACHINED SURFACES OF 1.5 PER CENT AND 2.0 PER CENT CHROMIUM CAST IRONS UNTREATED AND TREATED WITH SPECIAL LADLE ADDITIONS. (A) SPECIMEN 2, 1.51 PER CENT CHROMIUM, NO TREATMENT; (B) SPECIMEN 4, 1.51 PER CENT CHROMIUM, ALLOY 1 TREATED; (C) SPECIMEN 6, 1.45 PER CENT CHROMIUM, 0.5 PER CENT AS ALLOY 3; (D) SPECIMEN 8, 1.54 PER CENT CHROMIUM, NO TREATMENT; (E) SPECIMEN 3, 1.96 PER CENT CHROMIUM, NO TREATMENT; (F) SPECIMEN 5, 2.02 PER CENT CHROMIUM, ALLOY 1 TREATED; (G) SPECIMEN 7, 1.84 PER CENT CHROMIUM, 1.0 PER CENT CHROMIUM AS ALLOY 3; (H) SPECIMEN 9, 1.99 PER CENT CHROMIUM, NO TREATMENT.

The 2.0 per cent chromium alloy 3 treated iron (Specimen 7) was more easily machined than the straight chromium iron but not so readily machined as the alloy 1 treated iron. It would appear that at the 2.0 per cent chromium level, alloy 1 is more efficient than alloy 3 as regards its softening effect.

7. Table 3 and the observations on machining definitely indicate that a 1.5 per cent chromium iron can be strengthened and rendered machinable by ladle additions of alloy 1 or alloy 3. An alloy 1 addition to a 2.0 per cent chromium cast iron also improves the physical properties and renders an iron that would normally be unmachinable, machinable at relatively low speeds.

PROCEDURE USED IN OXIDATION AND GROWTH TESTS

8. The second object of this investigation was to study the deterioration of irons exposed to elevated temperature, and in particular to determine whether graphitization would adversely affect the resistance to such deterioration normally produced by additions of 1.5 per cent and 2.0 per cent chromium.

9. The test specimens employed in the major portion of this investigational work were six inch long bars cut from the middle portion of standard 1.2-in. diameter arbitration bars cast from the heats listed in Table 1. The cut ends of the 6-in. bars were machined flat, and to facilitate determinations of length changes (growth), stainless steel plugs were inserted[2] into each of the machined faces. The value of such inserts is that true overall length measurements can be obtained independent of errors normally brought about by scale formation.

10. These specimens were placed on stainless steel racks, and specimens and racks exposed to the test temperature 1472°F. (800°C.). A view of one of these racks and the manner in which a specimen rested on the rack is shown in Fig. 3.

11. In addition to the above specimens used both for growth and oxidation measurements, smaller oxidation specimens consisting of one-in. slices cut from the same arbitration bars were used to determine the rate of progressive oxidation. As described in a previous paper[1], these small oxidation specimens rested in depressions drilled in a 25 per cent chromium, 12 per cent nickel plate. They were exposed to the same heating cycles as the larger growth specimens.

12. A large Nichrome-wound furnace was used in heating the

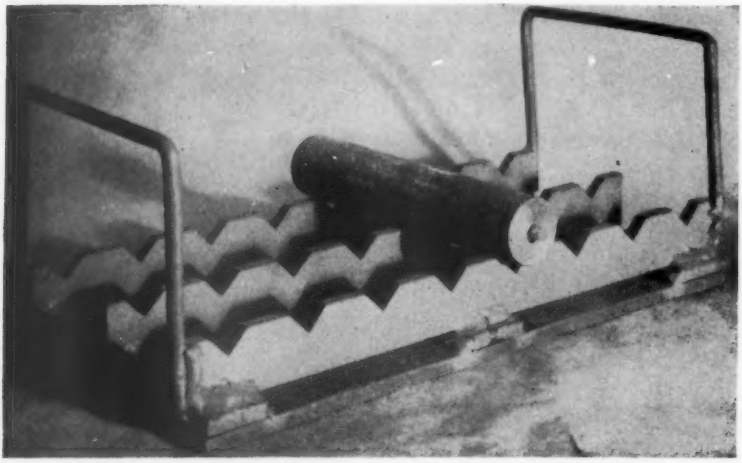

FIG. 3—TYPE OF RACK USED TO HOLD GROWTH SPECIMENS.

specimens to 1472°F. (800°C.). In a typical heating cycle, the furnace was brought to test temperature, and the specimens inserted. Approximately one hour was allowed for the specimens to reach 1472°F. (800°C.), and they were held at this temperature for an average period of 16 hours. The test specimens were then removed from the furnace and allowed to cool in still air to room temperature. This procedure was repeated until a total exposure time of 516 hours was attained.

13. The sixteen growth bars were measured after each heating cycle with a vernier caliper capable of measuring accurately to 0.001-in.

14. The small oxidation samples were weighed after each heating cycle. All loose scale was then removed and the samples reweighed before the next cycle. This latter precaution was taken to reduce flaking off of scale during the heating cycle to a minimum, and permit a comparatively accurate measurement of rate of scale formation to be obtained.

RESULTS OF OXIDATION TESTS

Rate of Progressive Oxidation

15. As noted in the preceding section, rate of progressive oxidation was determined by weighing the small oxidation samples after each heating cycle. The increase in weight on exposure to a heating cycle was considered as a measure of the rate of oxidation.

16. Curves of weight increase vs. time at temperature are shown for an unalloyed and 1.54 per cent chromium iron in Fig. 4. It will be noted that the rate of oxidation changes after approximately 72 hours at temperature. This is true of all cast irons, but is particularly evident in chromium-bearing irons on which a protective scale is gradually built up, the degree of protection increasing with chromium content. These detailed curves are included to indicate the method by which the slope of the curves of average rate of oxidation were obtained. It will be noted from the superimposed straight lines that the rate of oxidation is considered to correspond to the slope of the detailed weight gain-time curve after the 72nd hour, when the rate of gain has become fairly constant. This same procedure was used in determining the average rate of progressive oxidation of the other irons.

17. The manner in which chromium content from 0.50 per cent to 2.00 per cent affects the rate of progressive oxidation is shown diagrammatically in Fig. 5. It will be noted that a relatively sharp drop in the rate of progressive oxidation occurs with approximately 0.50 per cent chromium, and this rate of oxidation is further decreased with higher chromium contents. It might be noted in this regard that previous experience indicates that the effect of about 0.50 per cent chromium on oxidation rate can be masked or exaggerated by variations in the base iron at oxidation temperatures of 1472°F. or above, but when the chromium content reaches 1.0 per cent or over, the progressive oxidation rate shows a definite decrease irrespective of large variations in the type of base iron.

18. The curves of Fig. 5 represent the approximate effect of

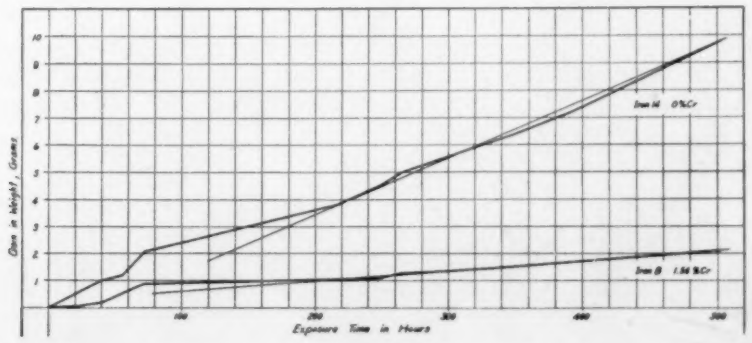

FIG. 4—PROGRESS WEIGHT INCREASE OF AN UNALLOYED CAST IRON AND A 1.50 PER CENT CHROMIUM CAST IRON.

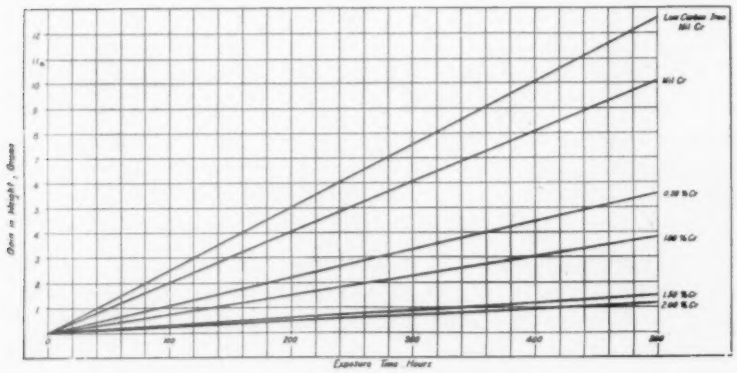

FIG. 5—RATES OF PROGRESSIVE OXIDATION.

chromium on reducing oxidation but they must be considered as approximate in view of the possibility that scale may have flaked off during a heating cycle. Their accuracy was increased by averaging the rates of oxidation of all specimens at a given chromium level and showing the rate at this chromium level as a single curve. Treatment of the 1.5 per cent and 2.0 per cent chromium irons with alloys 1, 2 or 3 did not produce any consistent variation in the progressive oxidation rates from those exhibited by ungraphitized irons of the same chromium content.

19. One interesting observation was the difference in progressive oxidation rate between the two unalloyed irons listed respectively as plain iron (Specimen 14) and low-carbon iron (Specimen 16). It should be stressed that both these irons were gray, the separation of flake graphite in the low-carbon iron being induced by an addition of alloy 1 or 2. The greater oxidation rate and final oxidation loss of the low-carbon iron appeared to be directly due to the fact that the scale formed on the iron did not adhere so firmly as it did on the higher carbon base iron. This is shown in

Table 4

ADHERENCE OF SCALE LAYERS ON UNALLOYED IRONS

Specimen No.	*Type*	*Before Exposure Original Weight, grams*	*After Exposure to 1472°F. (800°C.)*		*Total Wt. Loss on Cleaning, grams*
			Wt. Specimen Plus Scale, grams	*Change in Wt. from Original, grams*	
14	Base Iron	679.7	712.7	+ 33.0	89.5
16	Low-C Iron	720.2	675.3	— 44.9	113.9

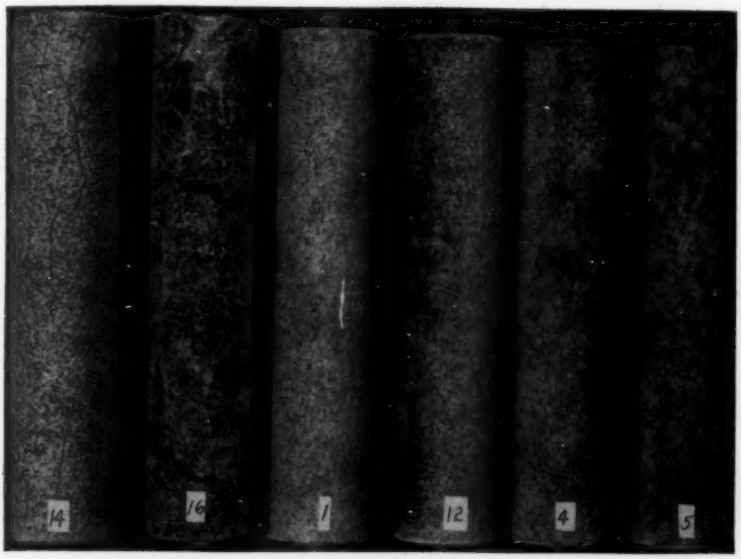

FIG. 6—APPEARANCE OF GROWTH SPECIMENS BEFORE CLEANING.

Table 4, which contrasts the original weight of a specimen with its weight after the formation of adhering scale on exposure to 1472°F. (800°C.).

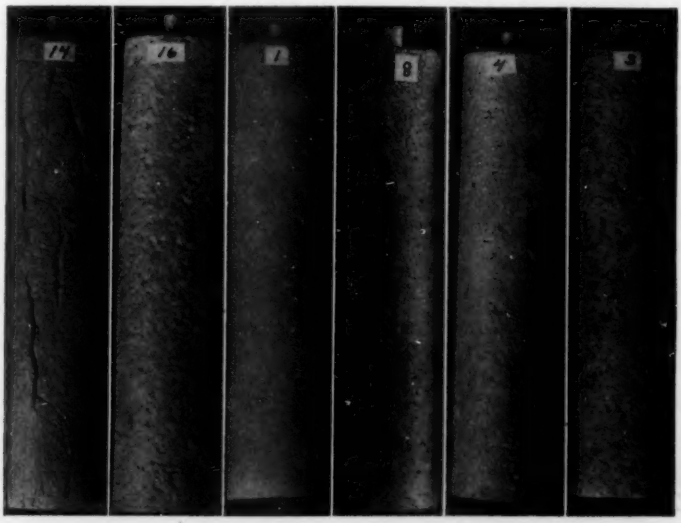

FIG. 7—APPEARANCE OF GROWTH SPECIMENS AFTER REMOVING SCALE.

20. It is clear from the fifth column of Table 4 that a considerable amount of the scale has broken off in the case of the low-carbon iron (Specimen 16), sufficiently so that a weight loss of 44.9 grams is recorded before sandblasting to remove tightly adhering scale. On the other hand, enough scale adheres to the plain base iron (Specimen 14) so that despite extensive oxidation, it shows before cleaning an increase of 33.0 grams over its original weight. Piwowarsky[3] has reported that the adhesion of scale on cast iron is far superior to that on steel in the range of 1380° to 1650°F. Presumably the graphitized low-carbon iron does not possess the adherent scale of a normal cast iron, resembling steel rather than cast iron in this regard.

21. Following the determinations of oxidation rate, the growth specimens were sandblasted to remove all adhering scale. The appearance of representative growth specimens before and after sandblasting is shown in Figs. 6 and 7. In Fig. 7 it will be noted that removal of scale from the unalloyed base iron (Specimen 14) reveals the presence of deep oxidation grooves that are believed to be associated with the high degree of internal oxidation exhibited by this iron. It will be noted that a small section has been cut from each of the growth bars in Fig. 7. These sections were removed previous to cleaning to permit metallographic examination of a section with adhering scale.

22. The per cent loss in weight and the loss in grams per sq. in. at 1472°F. of the growth specimens are shown in Figs. 8 and 9. Observation of individual points in these figures reveals some inconsistencies, but a very definite trend toward less oxidation loss with increasing chromium is evident. The largest drop in oxidation loss appears to take place as the chromium is raised from nil to 1.0 per cent chromium, although an appreciable and distinctly worth while improvement occurs on further raising the chromium to 1.5 and 2.0 per cent. It will be recalled that a somewhat parallel improvement with increasing chromium was noted in the resistance to progressive oxidation. It will be observed that there is no evidence that graphitization of the 1.5 and 2.0 per cent chromium cast irons by ladle additions produces a greater oxidation loss than in white irons of similar chromium content.

23. It is apparent from the curve in Fig. 9 that the simple addition of 1.5 per cent chromium to a cast iron will reduce its oxidation loss at 1472°F. to ⅛ that of an unalloyed iron. It is difficult

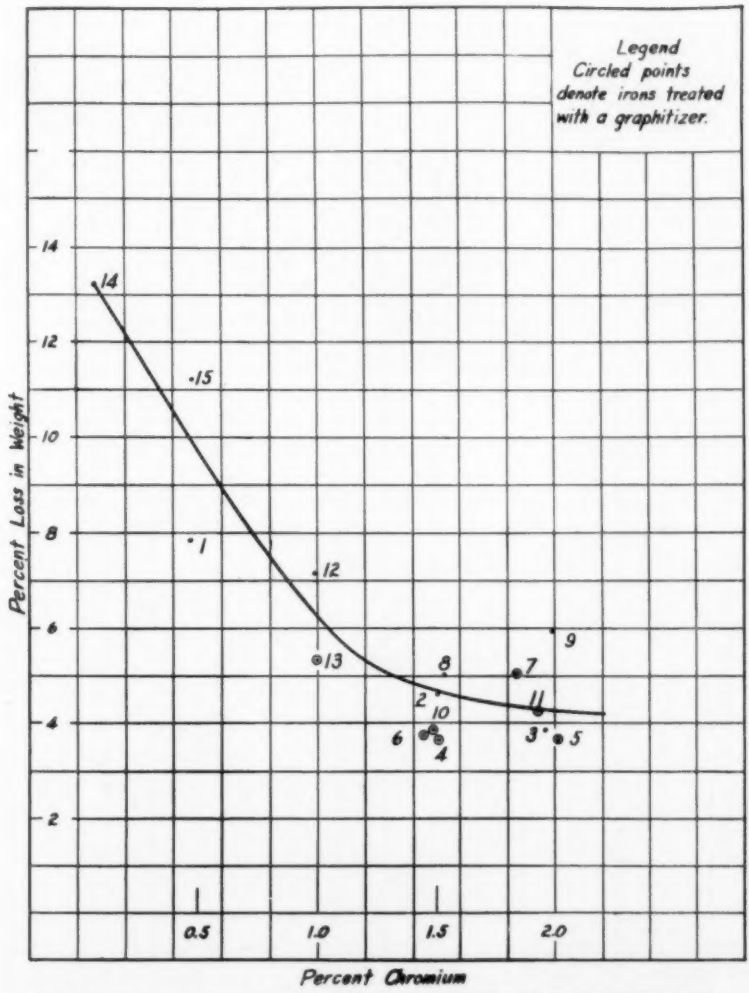

FIG. 8—PER CENT LOSS IN WEIGHT DUE TO OXIDATION OF GROWTH SPECIMENS.

to see how this effect can be brought about except through the formation of a more adherent and protective scale on the chromium-bearing irons. In order to permit a complete examination of the scale layers, sections were cut from the growth specimens with the scale still adhering. These were mounted with Wood's metal inside steel annular rings in order to preserve their scale during the polishing operation. The type of mounting employed is illustrated in Fig. 10. The appearance of the scale with increasing chromium content is

illustrated in Figs. 11 and 11-A. The scale on the unalloyed iron (Specimen 14) is light in color and, as evidenced by the numerous voids, very porous at the scale-metal interface. Only a portion of the scale of the unalloyed iron is shown, as actually its thickness covered three fields at 100 diameters. With 0.47 per cent chromium present in the iron (Specimen 1) the scale is obviously less porous

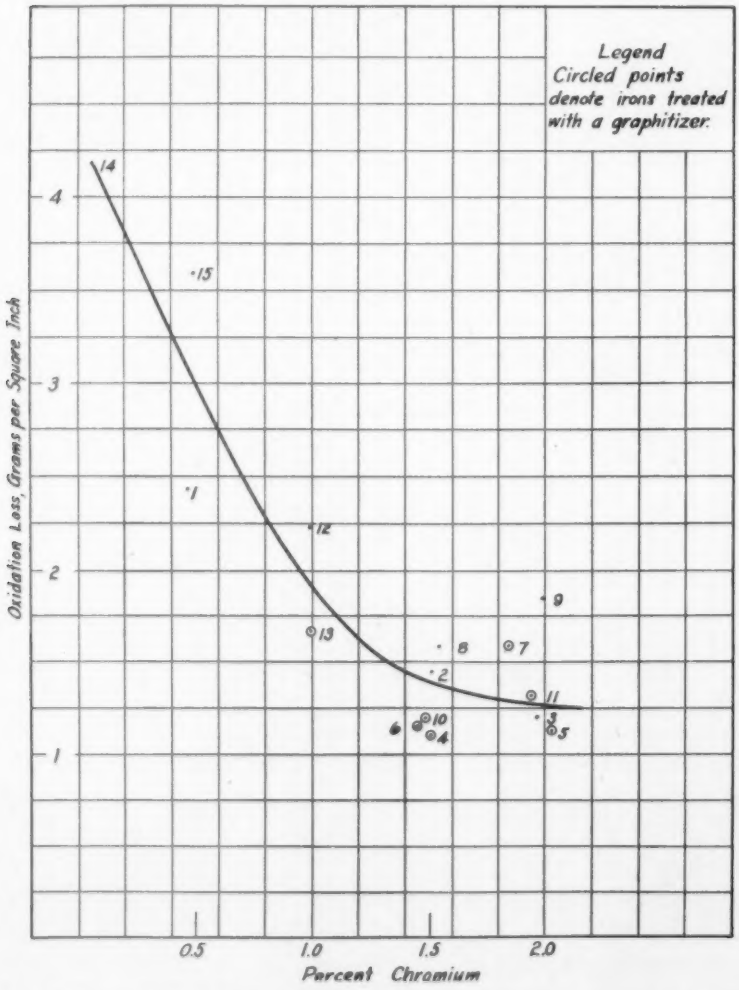

FIG. 9—LOSS IN WEIGHT IN GRAMS PER SQUARE INCH DUE TO THE OXIDATION OF GROWTH SPECIMENS.

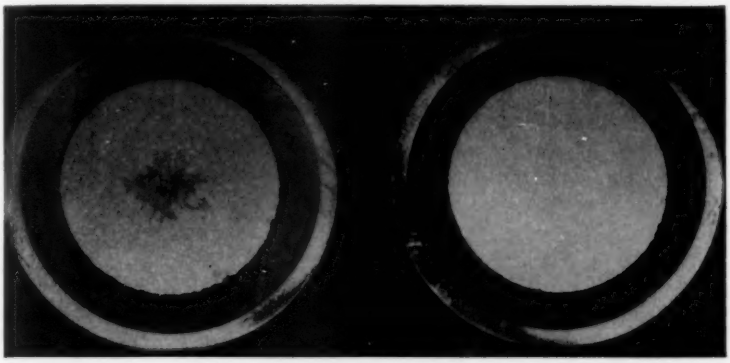

FIG. 10—ELIMINATION OF CENTER SHRINKAGE IN A 2.0 PER CENT CHROMIUM CAST IRON BY USE OF AN ADDITION ALLOY (X1). (LEFT) SPECIMEN 3, 1.96 PER CENT CHROMIUM, NO TREATMENT. (RIGHT) SPECIMEN 5, 2.02 PER CENT CHROMIUM, ALLOY 1 TREATED.

and begins to darken, particularly at the scale-metal interface. The scale thickness also decreases, so entire thickness of the scale is included in the photomicrographs from this chromium level on. As the chromium progressively increases to 0.99 per cent, 1.51 per cent and 1.96 per cent chromium this darkening continues and the scale has an extremely dense and homogeneous appearance at the two highest chromium contents. A further decrease in scale thickness also accompanies the increase in chromium content. The scale characteristics noted above were generally the same in the case of both graphitized and ungraphitized specimens.

24. Scale from each of the specimens was knocked off by light hammering and submitted to analysis. The scale analyses of the irons illustrated in Figs. 11 and 11-A are shown in Table 5.

25. It is interesting to observe that the scale on a chromium-bearing iron shows a definitely higher ratio of silicon to iron than that existing in the original cast iron, and when the chromium reaches approximately 1.5 per cent there is also a definitely higher ratio of chromium to iron in the scale than in the original iron. The scale on the unalloyed iron (Specimen 14), on the other hand, is slightly lower in silicon than the original iron. This lower ratio of silicon to iron in the scale was found in the case of the unalloyed low-carbon iron (Specimen 16) which also showed excessive oxidation. It would appear that in the protective scales formed on chromium-bearing irons not only is there an increase in relative chromium content but also a definite increase in silicon content over that present in the original irons. This condition appears to

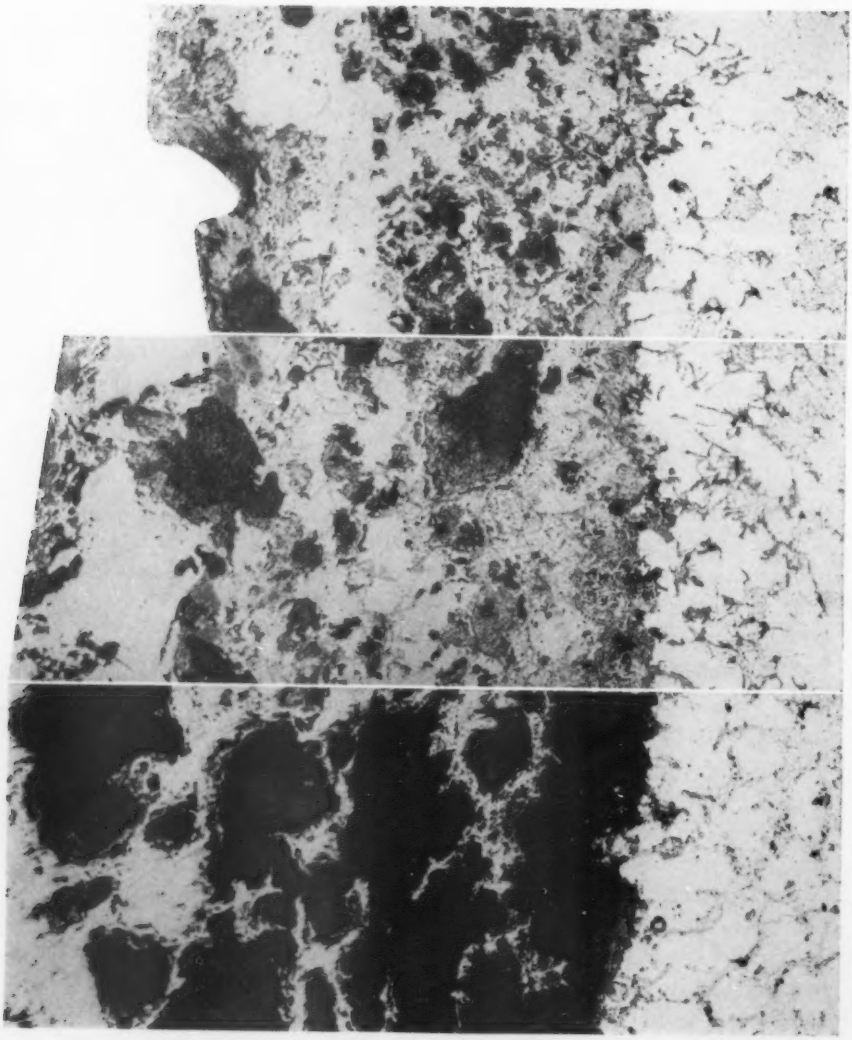

FIG. 11—SCALE FORMATION ON CAST IRONS OF VARYING CHROMIUM CONTENT AFTER EXPOSURE TO 1472°F. (X100). (LEFT) SPECIMEN 14, PLAIN. (CENTER) SPECIMEN 1, 0.47 PER CENT CHROMIUM. (RIGHT) SPECIMEN 12, 0.99 PER CENT CHROMIUM.

be a measure of good scale adherence and resistance to progressive oxidation.

26. The type and analysis of the scale formed on both graphitized and ungraphitized irons showed close agreement.

RESULTS OF GROWTH TESTS

27. As previously described, growth measurements were made after each heating cycle. The growth specimens have been illustrated in Fig. 6 and the accelerated growth of the unalloyed bars (Specimens 14 and 16) is at once apparent. From these readings curves of growth vs. time at 1472°F. could be plotted. Typical curves of growth with increasing time at temperature are shown for the plain and chromium-bearing irons in Fig. 12. It can be seen that there is a decided decrease in growth with the addition of approximately 0.50 per cent chromium, and a further decrease in growth with higher chromium contents until at the 2.0 per cent chromium level the growth is practically nil. It is interesting to observe that the rate of growth increases with time in the case of the

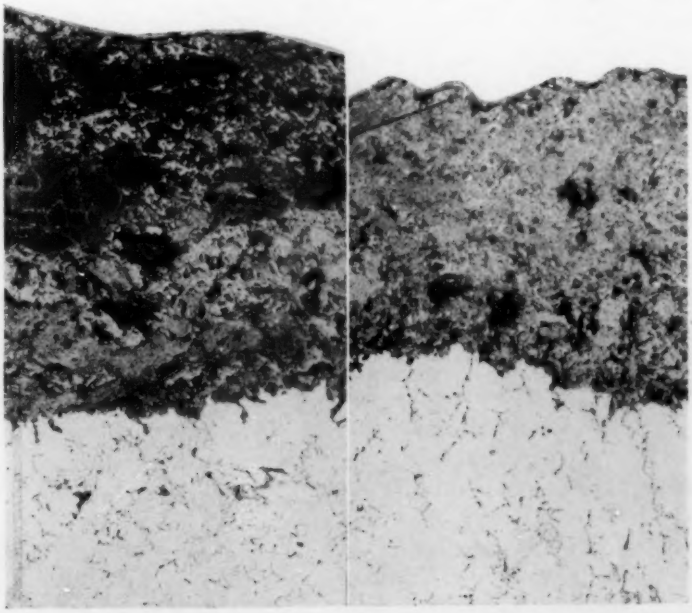

FIG. 11-A—SCALE FORMATION ON CAST IRONS OF VARYING CHROMIUM CONTENT AFTER EXPOSURE TO 1472°F. (X100). (LEFT) SPECIMEN 2, 1.51 PER CENT CHROMIUM. (RIGHT) SPECIMEN 3, 1.96 PER CENT CHROMIUM.

Table 5

CHEMICAL ANALYSIS OF SCALE ON UNALLOYED AND ALLOYED CAST IRON

Specimen No.	Treatment	Analysis of Scale: Silicon, Per Cent	Manganese, Per Cent	Chromium, Per Cent	Iron, Per Cent	Ratio Silicon to Iron: In Scale	In Bar	Ratio Chromium to Iron: In Scale	In Bar
14	No addition (Base Iron)	1.63	0.42	0.08	71.36	0.0229	0.0231	0.0011	0.0006
1	0.47% Cr F.G. FeCr	2.35	0.42	0.38	69.35	0.0339	0.0296	0.0055	0.0051
12	0.99% Cr F.G. FeCr	2.00	0.51	0.74	69.13	0.0290	0.0237	0.0107	0.0107
2	1.51% Cr F.G. FeCr	2.76	0.44	1.31	65.56	0.0420	0.0250	0.0200	0.0164
3	1.96% Cr FeCr	3.30	0.42	1.75	64.44	0.0513	0.0239	0.0272	0.0214

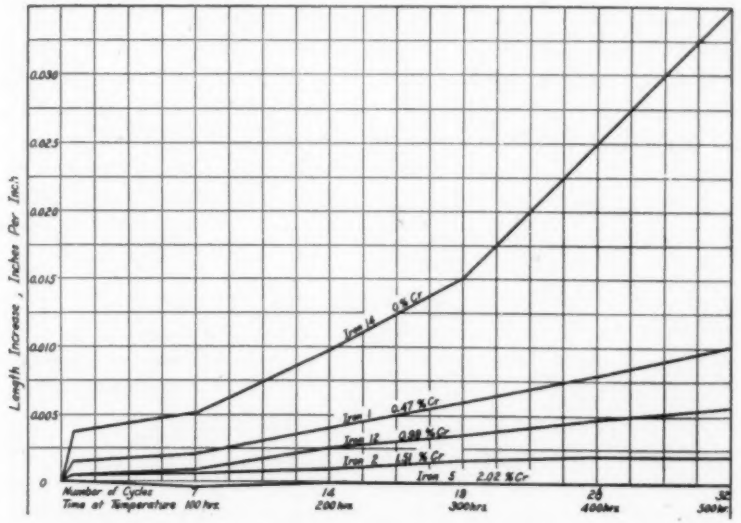

FIG. 12—GROWTH OF CAST IRON AFTER CYCLE HEATING TO 1472°F.

unalloyed iron while no such marked increase in growth rate with exposure time is noted in the case of the chromium-bearing irons, and in fact when the chromium reaches about 1.5 per cent there appears to be an actual decrease in growth rate with increasing exposure time. This may be connected with the formation of a progressively more protective scale on the higher chromium irons.

28. In Fig. 13, the total growth of each specimen is plotted against its chromium content, and it is possible to evaluate the effect of graphitizing treatments on the relative growth of chromium-bearing irons. In this figure the growth figures for the graphitized irons are surrounded by a circle. It is at once evident that up to and including a 1.5 per cent chromium content the growth of both graphitized and ungraphitized irons progressively decreases. However, at the 2.0 per cent chromium level we find the graphitized irons all showing practically nil growth, while the two white irons (Specimens 3 and 9) exhibit a growth much greater than would be expected from their high chromium content. This behavior of Specimens 3 and 9 was at first puzzling, for if a difference existed, it might be expected that the graphitized irons would show the most growth. The explanation, however, appears to be due to the fact that the growth bars of both irons 3 and 9 showed center shrinkage. The shrinkage in the case of iron 3 is

illustrated in Fig. 10. This shrinkage resulted from vertical casting of the bars and the use of comparatively small shrinkage heads. It is significant to observe that the addition of a graphitizer, as also shown in this same Fig. 10, was sufficient to eliminate shrinkage (Specimen 5). It is logical to assume that the internal shrinkage, which in several cases reached the surface, resulted in the exposure to oxidation of a much greater area of 3 and 9, and consequently produced abnormal oxidation and growth in these two

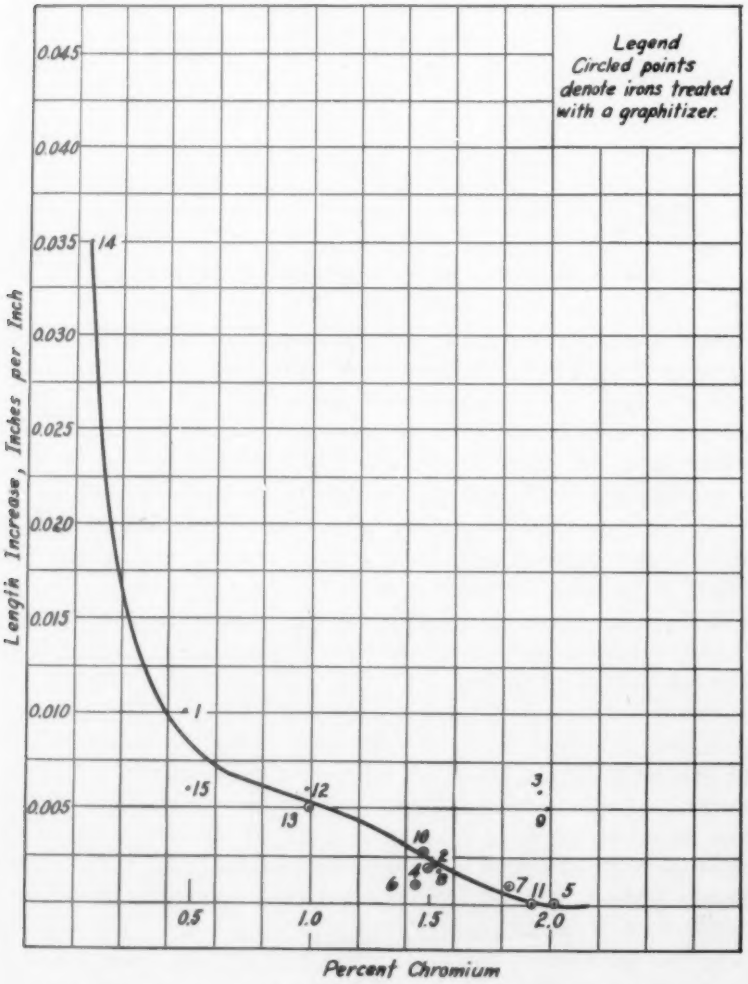

FIG. 13—TOTAL GROWTH IN INCHES AS A FUNCTION OF CHROMIUM CONTENT.

cases. In consideration of the above facts, the abnormal values for Specimens 3 and 9 were ignored in plotting the curves of Figs. 12 and 13.

CAUSES OF GROWTH AND INFLUENCE OF CHROMIUM ON GROWTH PHENOMENA

29. Opinion as to the factors producing growth in cast iron at elevated temperatures varies, but they are generally believed to be (1) decomposition of cementite, (2) occluded gases, (3) unequal expansion of the different constituents in the iron on heating, and (4) internal oxidation. In extended growth tests of the present type, we are not primarily concerned with the decomposition of cementite to iron and graphite, which produces only a fraction of the growth of cast iron, but with phenomena probably of an oxidation nature, that produce a continuous growth and a deterioration in the physical properties of cast iron throughout extended exposure to high temperature. In a previous paper[1] the formation of a "metal-oxide" constituent in the metal proper below the scale layer was noted and briefly described. The formation of this constituent is believed to be the chief factor in the growth and deterioration of cast iron and far overshadows any of the other factors noted above.

30. The purpose of the present section of the investigation was to determine first whether the occurrence and the quantity of the "metal-oxide" constituent was related to the relative growth and deterioration shown by the irons. A second purpose was to determine whether chromium in solution in the iron was mainly responsible for the elimination of the "metal-oxide" constituent or whether its elimination was due to the fact that graphite flakes, the avenues for penetration of oxidizing gases, were decreased and finally virtually eliminated when the chromium reached the range of 1.0 to 2.0 per cent. A third object was to determine whether the so-called "metal-oxide" constituent actually was a metal oxide. The previous basis for this term rested merely on the observations[1] that a fine precipitate was evident in the metal-oxide areas such as might be caused by a precipitation of iron oxide from a saturated ferrite, and that cracking of these areas occurred on alternate heating and cooling, indicating the formation of a voluminous precipitate such as iron oxide.

31. In the present series of irons the metal-oxide constituent[1] again formed on prolonged exposure to 1472°F. of irons containing

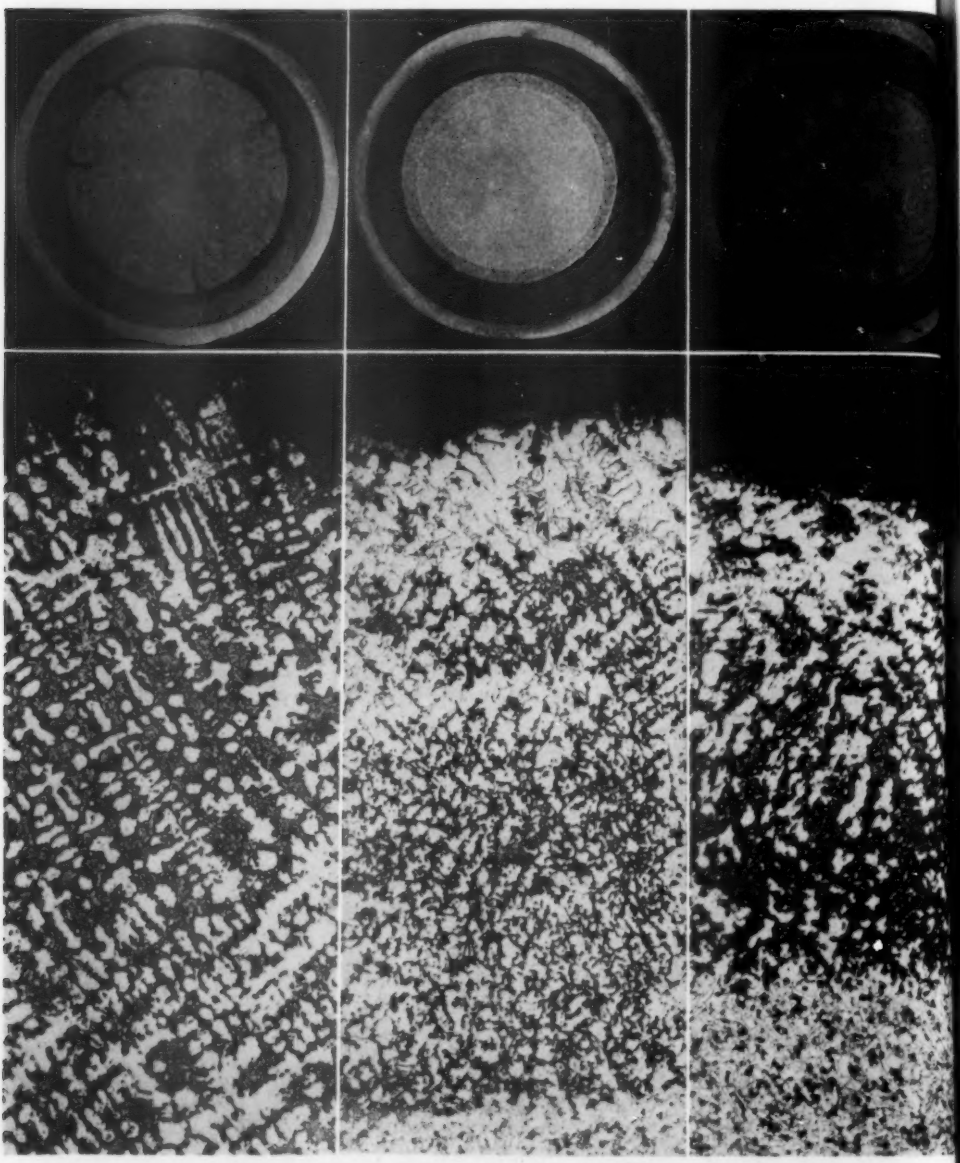

FIG. 14—ELIMINATION OF "METAL-OXIDE" LAYER WITH INCREASING CHROMIUM CONTENT (X50). (LEFT) SPECIMEN 14, UNALLOYED IRON. (CENTER) SPECIMEN 1, 0.47 PER CENT CHROMIUM. (RIGHT) SPECIMEN 12, 0.99 PER CENT CHROMIUM.

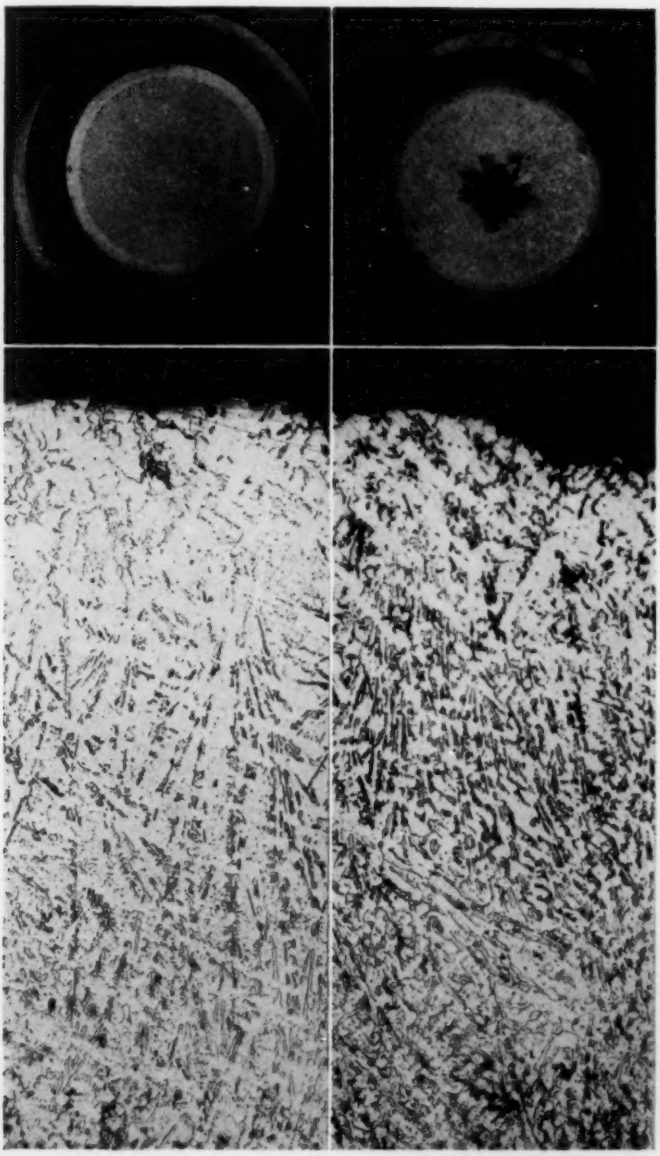

FIG. 14-A—ELIMINATION OF "METAL-OXIDE" LAYER WITH INCREASING CHROMIUM CONTENT (X50). (LEFT) SPECIMEN 2, 1.51 PER CENT CHROMIUM. (RIGHT) SPECIMEN 3, 1.96 PER CENT CHROMIUM.

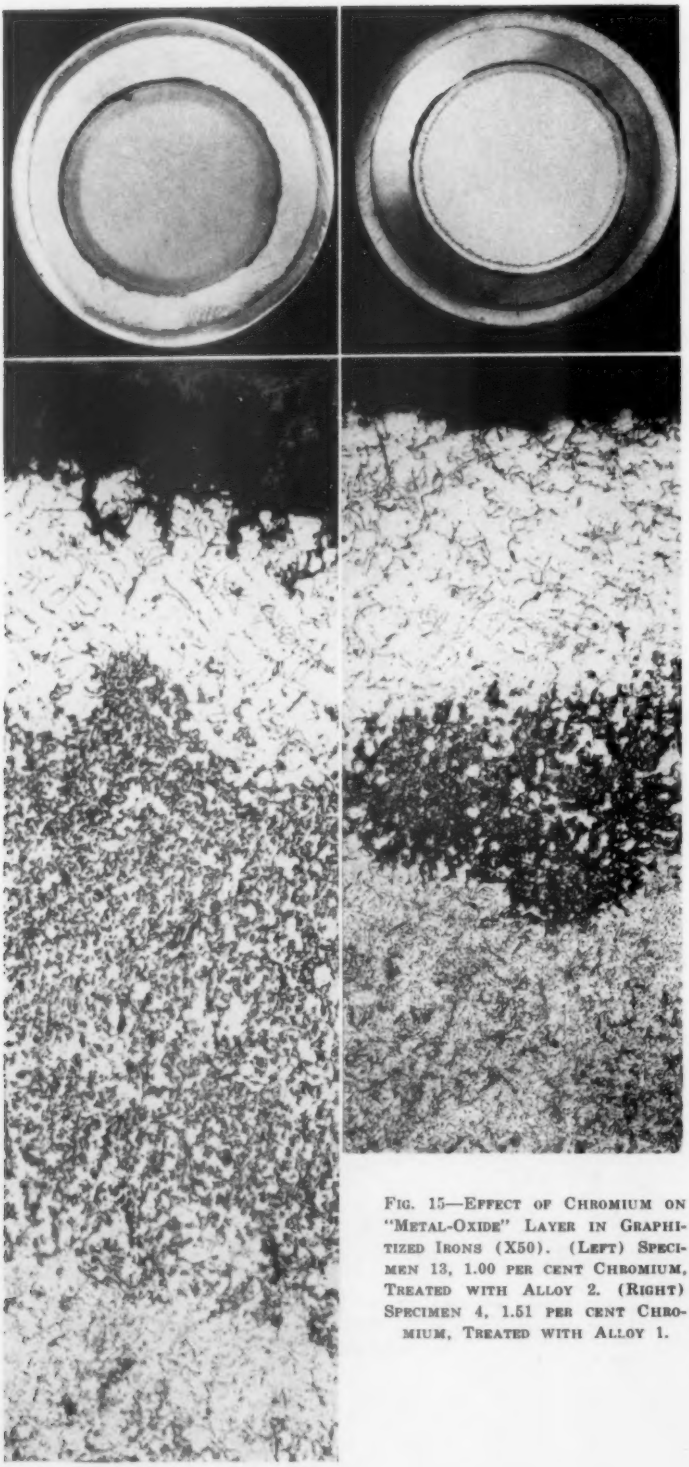

FIG. 15—EFFECT OF CHROMIUM ON "METAL-OXIDE" LAYER IN GRAPHITIZED IRONS (X50). (LEFT) SPECIMEN 13, 1.00 PER CENT CHROMIUM, TREATED WITH ALLOY 2. (RIGHT) SPECIMEN 4, 1.51 PER CENT CHROMIUM, TREATED WITH ALLOY 1.

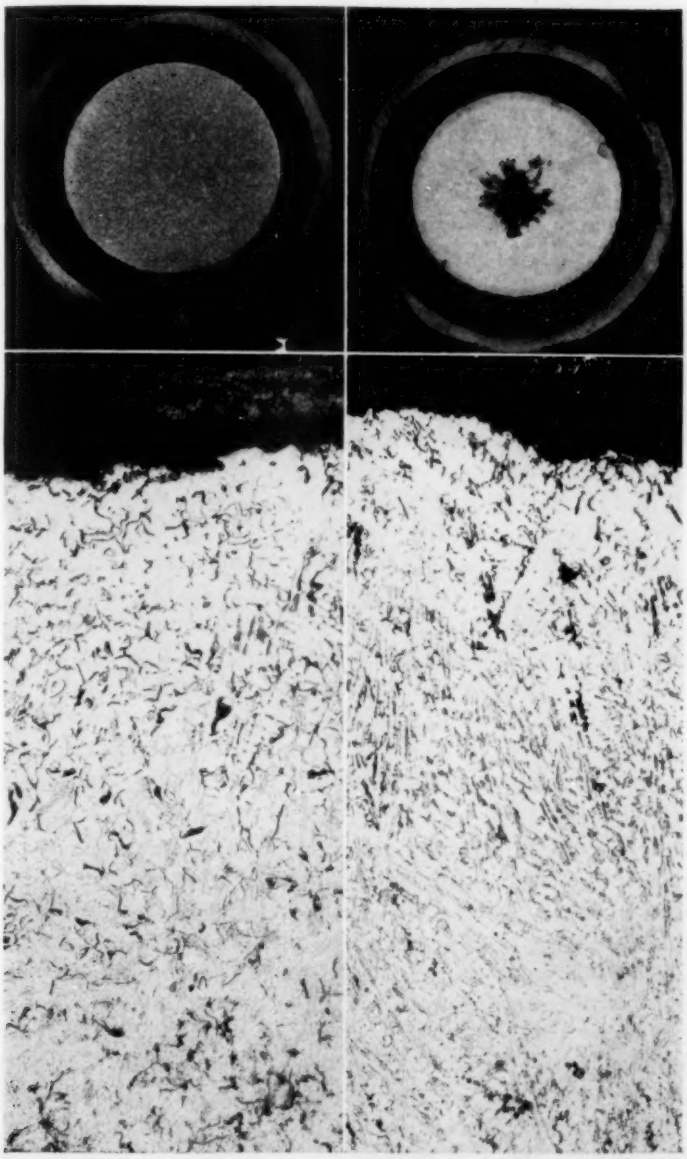

FIG. 15-A—EFFECT OF CHROMIUM ON "METAL-OXIDE" LAYER IN GRAPHITIZED IRONS (X50). (LEFT) SPECIMEN 5, 2.02 PER CENT CHROMIUM, TREATED WITH ALLOY 1. (RIGHT) SPECIMEN 3, 1.96 PER CENT CHROMIUM, NO TREATMENT.

less than 1.5 per cent chromium. This is illustrated in Figs. 14 and 14-A which illustrate at the top of the figure the appearance of the sectioned growth bars taken at normal magnification. Immediately beneath each macrograph the structure of the iron in the surface layer is shown at 50 diameters. It will be noted that in the unalloyed base iron (Specimen 14) the dark etching "metal-oxide" layer extends at least 0.30-in. below the surface, and some major cracking has occurred in this layer. Actually, as subsequently described, small amounts of the "metal-oxide" constituent were found extending to the center of this unalloyed specimen, and their presence is confirmed by gas analysis of the core of the specimen. When approximately 0.50 per cent chromium is present as in Specimen 1, the "metal-oxide" constituent is confined to a definite layer extending approximately 0.075-in. beneath the metal surface. The thickness of this layer is further reduced to about 0.05-in. by raising the chromium to approximately 1.0 per cent, as shown in Specimen 12. In Specimen 2, containing approximately 1.5 per cent chromium, the "metal-oxide" constituent is no longer readily distinguished. In this sample a simple decarburized layer has apparently replaced the "metal-oxide" layer. In the case of the 2.0 per cent chromium cast iron (Specimen 3) this surface decarburization is reduced to a narrow layer. It will be recalled from Fig. 12 that the growth similarly falls to a negligible value at 1.5 per cent chromium and is practically nil at a 2.0 per cent chromium level. A definite relationship therefore exists between the gradual reduction and elimination of growth and the gradual reduction and elimination of the "metal-oxide" constituent.

32. In regard to the second purpose of the investigation, *i.e.*, to determine whether chromium alone will prevent penetration of "metal oxide" even in the presence of profuse graphite, the graphitized series of irons furnishes an answer. A similar decrease in the "metal-oxide" layer with increasing chromium is observed in the case of the graphitized 1.0 per cent chromium (Specimen 13), 1.5 per cent chromium (Specimen 4) and the 2.0 per cent chromium (Specimen 5) irons. This is illustrated in Figs. 15 and 15-A. It is evident that chromium alone will inhibit penetration of the "metal-oxide" constituent even in the presence of profuse graphite. This information is of particular interest as it definitely demonstrates that chromium in solution in cast iron is of primary importance in limiting internal oxidation of low-alloy cast irons, and that such decrease in oxidation is not mainly due to the elimi-

nation of graphite.

33. Although in both cases chromium reduces penetration of "metal-oxide" to a negligible value, there is an apparent difference in the appearance of the "metal-oxide" layers of graphitized specimens and ungraphitized specimens of approximately equal chromium content. The graphitized specimens at normal and 50 magnifications are shown in Figs. 15 and 15-A and should be contrasted with the corresponding ungraphitized Specimens 12, 2 and 3 in Figs. 14 and 14-A. It will be noted that at the 1.0 per cent chromium level the "metal-oxide" layer is deeper but that it is not continuous to the surface as in the ungraphitized specimens. At the 1.5 per cent chromium level a very narrow line of "metal-oxide" is still evident but a wide decarburized band apparently free from oxide exists between the "metal-oxide" layer and the surface. No "metal-oxide" layer is apparent in the 2.0 per cent chromium graphitized iron, and it closely resembles the ungraphitized 2.0 per cent chromium specimen.

34. On first glance it would appear from these observations that the graphitized irons permit slightly deeper penetration of the "metal-oxide" constituent. That this difference is of a minor nature is shown by the fact that the graphitized irons do not show greater oxidation loss (Fig. 9) or growth (Fig. 13) than the ungraphitized irons, and in fact, on the average, possess equal or superior resistance to these deteriorating effects. One possibility is that formation of a critical amount of "metal-oxide" constituent in the graphitized irons does not produce the same amount of scaling as in the ungraphitized irons. This greater adherence may be due to the gray character and more profuse graphite of the graphitized irons which would be in accord with Piwowarsky's observations[2], and the observations in the case of the high and low-carbon base irons. If this mechanism is operative any small localized formation of "metal-oxide" layer in the ungraphitized chromium cast irons may have been sloughed away, while in the graphitized irons traces of such a constituent would remain. It appears possible from observation of the outer ferrite layers on Specimens 4 and 13 in Figs. 15 and 15-A that when this "metal-oxide" constituent does remain in a high chromium iron, it can be reduced or eliminated under certain critical temperature or oxygen concentration conditions, presumably by interaction of the "metal-oxide" with the remaining graphite or carbide in the outer layer.

35. In regard to the third object, *i.e.*, the determination of the

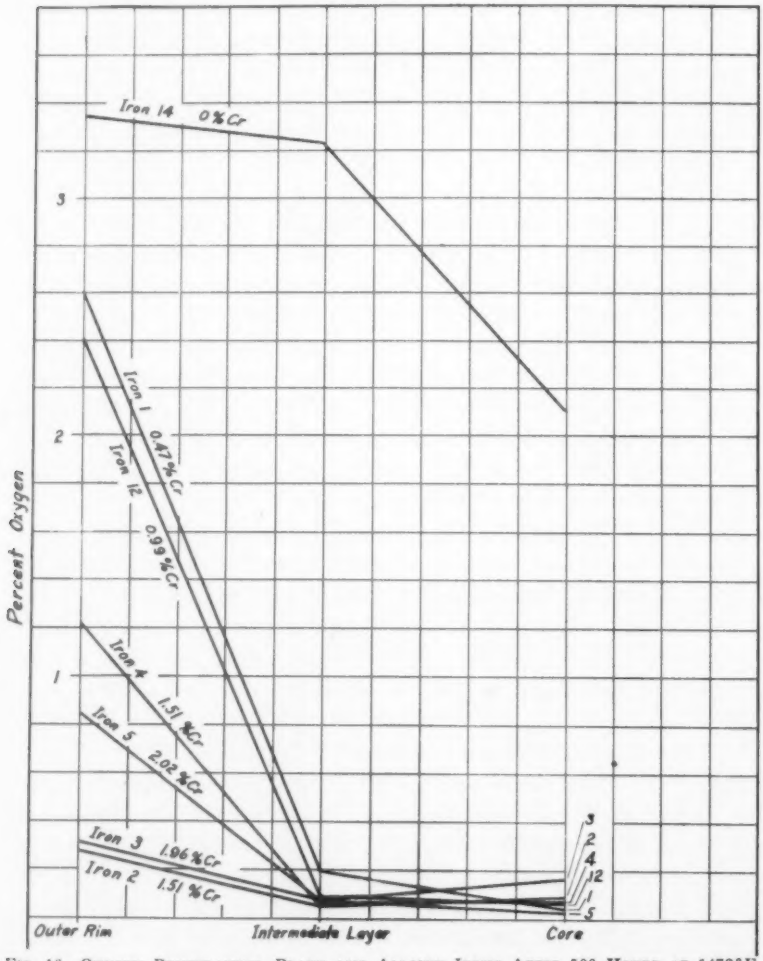

FIG. 16—OXYGEN PENETRATION, PLAIN AND ALLOYED IRONS AFTER 500 HOURS AT 1472°F.

character of the "metal-oxide" constituent, it has been assumed that the constituent contains a significant amount of iron oxide but no proof has been advanced that such is the case. To settle this point successive layers were machined from representative growth bars after sandblasting to remove all adhering scale. The typical appearance of the cross sections of these growth bars has been illustrated in Figs. 14, 14-A, 15 and 15-A. The first metallic layer taken from the 1⅛-in. diameter bars for analysis was $\frac{1}{16}$-in. in thickness. The second layer immediately beneath the first layer was

⅛-in. in thickness. The last material for analysis consisted of turnings taken from the complete cross section of the remaining core. The results of the oxygen analyses on these sections, called outer layer, intermediate layer, and core, respectively, are given in Table 6. The oxygen analyses are shown graphically in Fig. 16. It should be stressed that these analyses were made on the metallic portion of the specimens, all detectable adhering scale having been previously removed by careful cleaning and sandblasting.

Table 6

OXYGEN CONTENT OF CAST IRONS AFTER EXPOSURE TO 1472°F.

Specimen No.	*Heat No.*	*Treatment*	*Outside Rim ⅛-in. Cut, Oxygen, per cent*	*Intermediate Layer, ⅛-in. Cut, Oxygen, per cent*	*Core Oxygen, per cent*
16	B-4	Low-carbon Base Iron	3.67	2.83	1.63
14	8925	Base Iron	3.36	3.23	2.10
1	8193	0.47% Cr	2.61	0.27	0.04
12	8835	0.99% Cr	2.41	0.08	0.06
2	8757	1.51% Cr	0.28	0.05	0.09
4	8759	1.51% Cr*	1.22	0.04	0.07
3	8758	1.96% Cr	0.31	0.08	0.17
5	8760	2.02% Cr*	0.85	0.07	0.03

36. It is at once clear from Table 6 and Fig. 16 that the base iron to which no chromium additions were made contains a high percentage of oxygen, over 2.0 per cent by weight, even in the core. It had been noted in the metallographic examination that the "metal-oxide" constituent actually extended into the core in this specimen, as illustrated in Fig. 17. The presence of 0.47 per cent chromium slightly reduces the oxygen content of the outside layer and sharply reduces the oxygen content in the intermediate layer and core. This is in accordance with observations that the presence of chromium inhibits the penetration of the "metal-oxide" constituent. With further increase in chromium content to approximately 1.0 per cent and above, the oxygen present in the outside layer progressively decreases. The intermediate layers and the cores show approximately constant low oxygen values after a 1.0 per cent chromium content is reached and exceeded. It is worthy of note that the graphitized irons 4 and 5 show a greater amount of oxygen in the outer rim than irons 2 and 3, of comparable chromium content but not receiving graphitizer additions. As far as irons 4 and 2 are concerned, this is in accordance with the metallographic examination in which graphitized iron 4 showed a narrow band of metal oxide against only traces of metal oxide in the ungraphitized iron 2. However, it is not so clear why graphitized iron

* Treated with graphitizer.

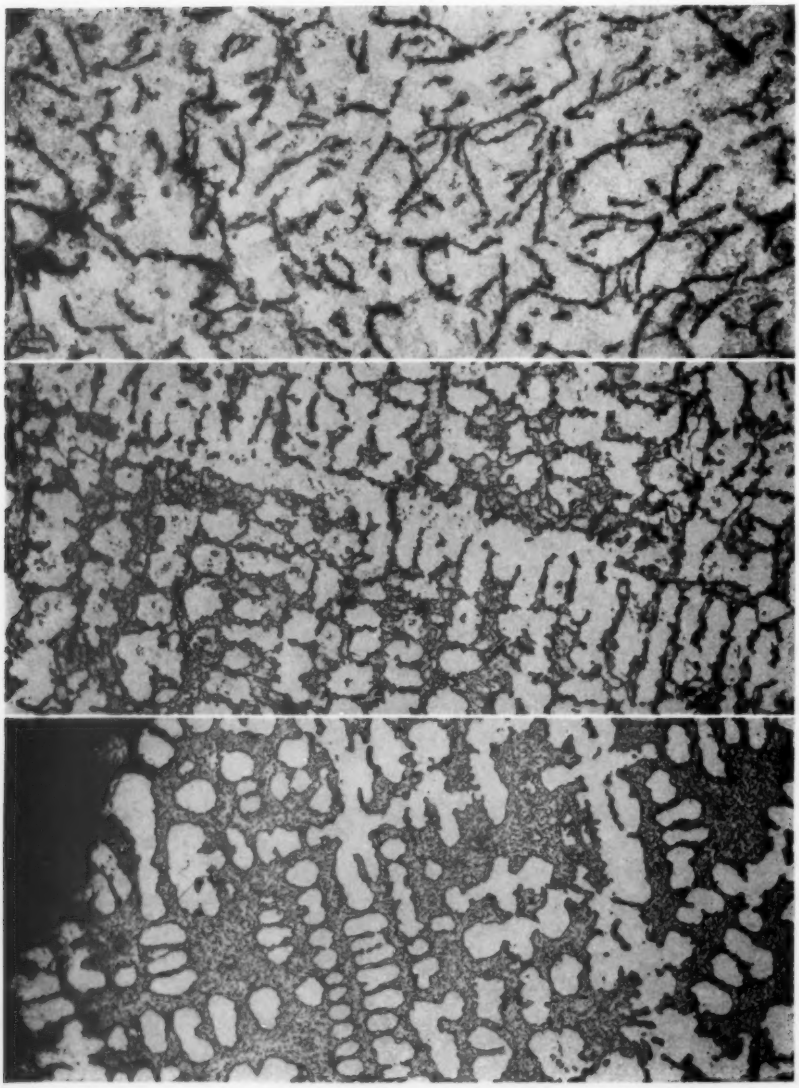

FIG. 17—OCCURRENCE OF "METAL-OXIDE" CONSTITUENT FROM OUTER EDGE TO CENTER OF BASE IRON (UNALLOYED IRON, SPECIMEN 14, X100). (LEFT) EDGE. (CENTER) MIDWAY BETWEEN EDGE AND CENTER. (RIGHT) CENTER.

5 containing 2.02 per cent chromium should show a higher oxygen content at the surface than iron 2 containing 1.51 per cent chromium. Neither of these irons shows definite formation of "metal-oxide," although some evidence is available to indicate that an occasional isolated small area of this constituent may exist at the extreme surface in both irons. The difference between irons 2 and 5, however, is relatively small and may lie within the range of accuracy of the methods of sampling and gas analysis.

37. Assuming that a greater quantity of "metal-oxide" constituent forms in the graphitized irons due to a slightly deeper penetration of oxygen, it is still clear from the oxygen analyses that composition of the groundmass of the iron is more important in limiting internal oxidation and growth than the initial presence or absence of graphite flakes as avenues for penetration of oxidizing gases. Thus a marked decrease in the oxygen content and in penetration of the "metal-oxide" constituent occurs in the case of the graphitized iron 4 containing 1.51 per cent chromium, as compared to ungraphitized iron 12 containing 0.99 per cent chromium even though the 1.51 per cent chromium iron originally contained more profuse and larger graphite flakes.

38. The oxygen analyses of Table 6 definitely establish the fact that the "metal-oxide constituent contains a high percentage of oxygen. As would be expected, its formation also coincides with a drastic decrease in carbon content, as shown in Table 7.

Table 7

VARIATION IN CARBON CONTENT OF CAST IRONS AFTER EXPOSURE TO 1472°F.

Specimen No.	*Heat No.*	*Treatment*	*Carbon Content After Exposure, per cent* — *Outside Rim. 1/10-in. Cut*	*Intermediate Layer. 1/5-in. Cut*	*Core, per cent*	*Original Carbon Content Before Exposure, per cent*
16	B-4	Low-carbon Base Iron	0.13	0.49	2.35	2.38
14	8925	Base Iron	0.20	0.84	3.01	3.18
1	8193	0.47% Cr	0.38	2.87	3.17	3.15
12	8835	0.99% Cr	0.71	3.17	3.21	3.21
2	8757	1.51% Cr	0.89	3.29	3.39	3.38
4	8759	1.51% Cr*	1.84	3.22	3.31	3.29
3	8758	1.96% Cr	1.16	3.21	3.29	3.33
5	8760	2.02% Cr*	1.71	3.25	3.36	3.35

39. Estimation of the actual oxygen content of the "metal-oxide" constituent is most readily made in the case of the unalloyed iron (Specimen 14). The constituent occupies approximately 50

* Treated with graphitizer.

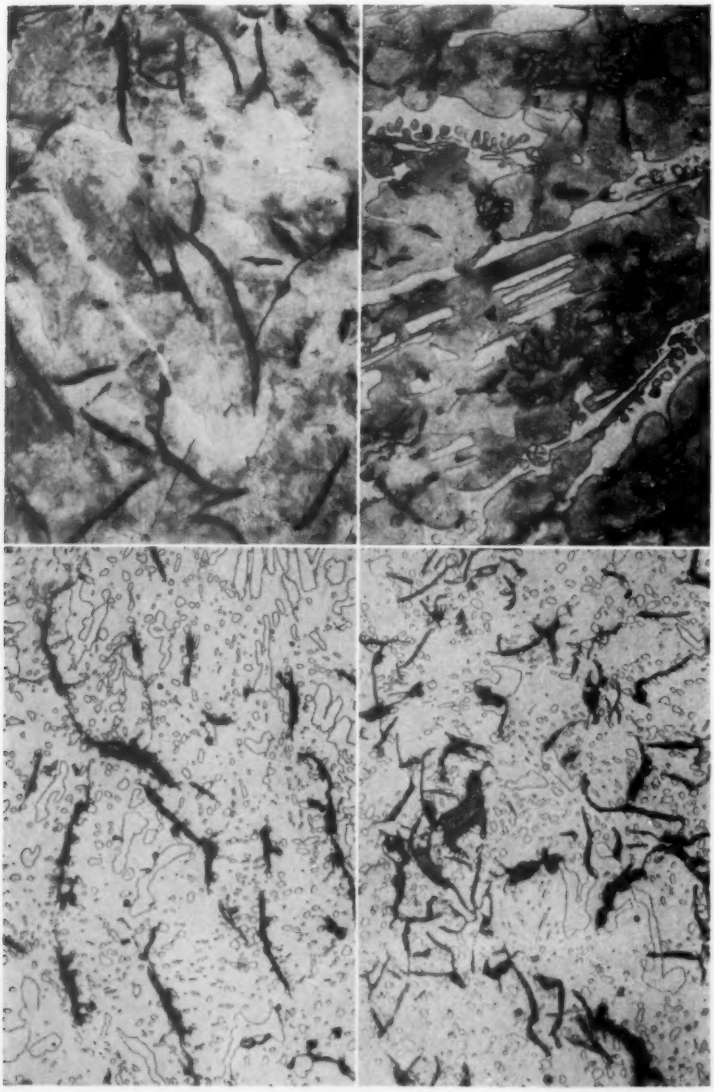

FIG. 18—COMPARATIVE STRUCTURES OF 1.5 PER CENT CHROMIUM CAST IRONS BEFORE AND AFTER EXPOSURE TO 1472°F. (ABOVE) BEFORE EXPOSURE. (BELOW) AFTER EXPOSURE. (LEFT) GRAPHITIZED. (RIGHT) PLAIN.

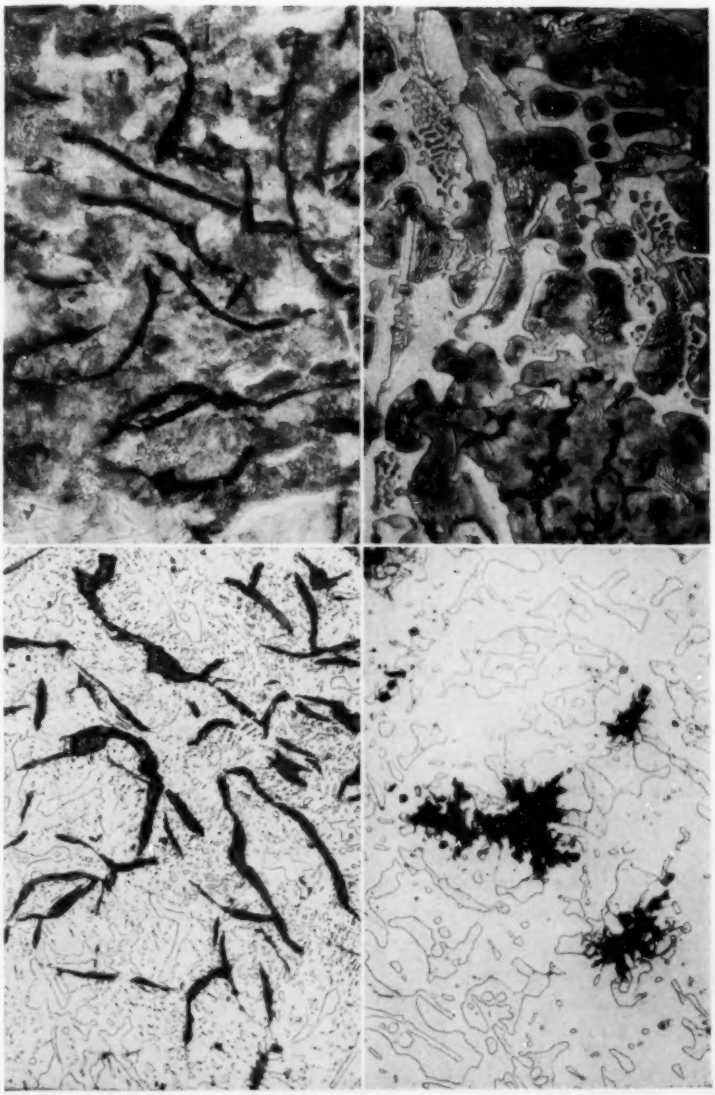

FIG. 18-A—COMPARATIVE STRUCTURES OF 2.0 PER CENT CHROMIUM CAST IRONS BEFORE AND AFTER EXPOSURE TO 1472°F. (ABOVE) BEFORE EXPOSURE. (BELOW) AFTER EXPOSURE. (LEFT) GRAPHITIZED. (RIGHT) PLAIN.

per cent of the groundmass of the outer layer of this iron, as shown in Fig. 17, and the oxygen content of the whole layer is shown in Table 6 to be approximately 3.5 per cent. This would mean that the "metal-oxide" constituent itself contains approximately 7.0 per cent oxygen. This oxygen content is lower than that of any known iron oxide but the possibility exists that the "metal-oxide" areas actually consist of an almost submicroscopic precipitate of some known ferrous oxide. Against this simple explanation is the fact that a diffraction pattern taken on this outside layer showed the presence of a crystalline material that does not correspond to any known oxide or silicate. The possibility of the formation of a silicate is also negated by the fact that the residue left, on an electrolytic separation, is mainly iron and not silicate. Therefore, at least a possibility exists that the "metal-oxide" constituent is a ferrous oxide in too fine a state of dispersion to yield a definite pattern or is a compound not previously identified.

STRUCTURE AND PHYSICAL PROPERTIES OF CAST IRONS AFTER PROLONGED EXPOSURE TO 1472°F.

40. As noted above, the presence of approximately 0.50 per cent chromium prevented penetration of the "metal-oxide" constituent to the core of specimens held at 1472°F. In the irons containing 0.50 per cent chromium or more, it is, therefore, possible to determine structural changes in the metal proper that result from the prolonged exposure to this temperature. In all cases there was a distinct decrease in the amount of lamellar pearlite. This decrease appeared to result from a spheroidizing process, *i.e.*, the formation of relatively large spheroids of cementite from the original cementite of the pearlite. The addition of graphitizing alloys to the irons containing 0.5 per cent and 1.0 per cent chromium appeared to increase this spheroidizing action. The normal breakdown of these spheroids to graphite and ferrite is obviously delayed by the stabilizing effect of chromium.

41. When chromium reached 1.5 per cent and 2.0 per cent levels, pearlite practically disappeared. This is shown in Figs. 18 and 18-A which contrast the typical appearance of the graphitized and ungraphitized 1.5 per cent and 2.0 per cent chromium irons before and after their exposure for 516 hours at 1472°F.

42. Tensile tests were made to determine to what degree chromium prevents the severe weakening and embrittling that normally

follow prolonged exposure of unalloyed cast iron to high temperatures. The standard cast iron tensile specimens were turned out of the growth bars, which had been exposed to a temperature of 1472°F. for 516 hours. The strength after exposure is contrasted with the original as-cast strength of the iron in Fig. 19.

43. It is at once clear that in the absence of chromium a very serious loss in strength occurs on prolonged exposure to 1472°F.

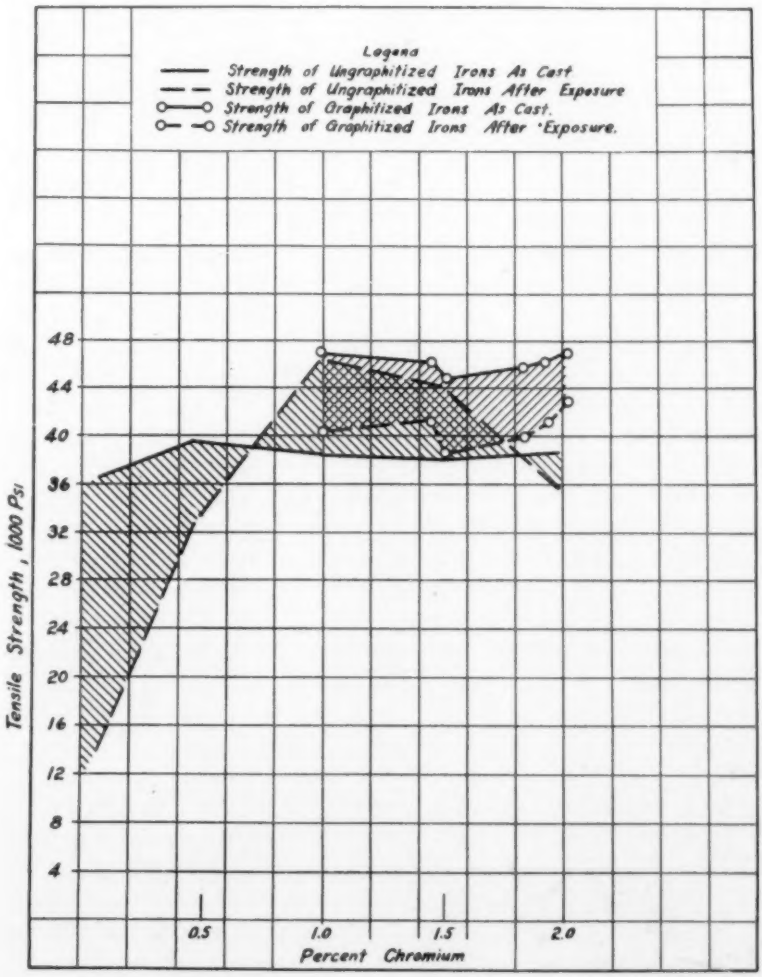

FIG. 19—STRENGTH CHANGE OF PLAIN AND ALLOYED IRONS EXPOSED TO 1472°F.

This loss amounts to some 62 per cent in the unalloyed base iron. With as little as 0.50 per cent chromium present in the irons, the loss is cut to 16 per cent, and with percentages of 1.0 per cent to 2.0 per cent chromium the change in strength is negligible.

44. There is actually a slight strength gain in the case of the ungraphitized irons containing 1.0 per cent and 1.5 per cent chromium*, and a slight strength decrease in the case of graphitized 1.0 per cent to 2 per cent chromium irons. It would appear that the maximum strength of a 1.0 per cent to 2 per cent chromium iron depends on the production of a critical degree of graphitization, and after this is reached (as in the case of the graphitized irons) a slight strength loss may be recorded due to a spheroidizing or softening effect. That such softening has proceeded to a greater degree in the graphitized irons is indicated in Table 8.

Table 8

CHANGE IN HARDNESS OF CAST IRONS PRODUCED BY EXPOSURE TO 1472°F.

Specimen No.	*Heat No.*	*Chromium, Per Cent*	*Treatment*	*Original Hardness*	*Hardness After Anneal*
16	B-4	0.01	Low Carbon Base Iron	235	153
14	8925	0.06	Base Iron	228	159
1	8193	0.47	F.G. FeCr	217	170
15	A-3	0.49	Alloy 3	228	174
12	8835	0.99	F.G. FeCr	321	248
13	8925	1.00	F.G. FeCr + Alloy 1	269	217
2	8757	1.51	F.G. FeCr	332	269
8	8763	1.54	Mn FeCr	364	293
4	8759	1.51	F.G. FeCr + Alloy 1	286	217
6	8761	1.45	F.G. FeCr + Alloy 3	302	223
10	8765	1.48	F.G. FeCr + Alloy 3**	286	217
3	8758	1.96	F.G. FeCr	512	340
9	8764	1.99	Mn FeCr	495	332
5	8760	2.02	F.G. FeCr + Alloy 1	321	255
7	8762	1.84	F.G. FeCr + Alloy 3	387	302
11	8766	1.93	FeCr + Alloy 3**	364	286

SUMMARY

45. The present experiments have shown that by the use of graphitizers of the silicon-manganese-zirconium type, irons normally white or unmachinable because of chromium contents of 1.5 per cent and 2.0 per cent, can be effectively softened and brought within the machinable range. This object is accomplished without ma-

* The ungraphitized 2.0 per cent chromium tensile specimen tested after exposure, showed a defective break due to original center shrinkage.
** Small ore addition.

terially changing the base analysis from that commonly used. This development would appear of primary importance as it permits advantage to be taken of the superior heat resistance, growth resistance, and general stability of irons containing 1.0 per cent to 2.0 per cent chromium, without an excessive sacrifice in toughness and machinability.

46. It has been found that the rate of progressive oxidation of cast iron and the total loss in weight by oxidation are materially decreased with small chromium contents. For example, the rate of progressive oxidation at 1472°F. (800°C.) of a 1.5 per cent chromium cast iron is only about 1/5 that of an unalloyed iron, and its total loss in weight only about ⅛ that of an unalloyed iron after 516 hours at test temperature. No consistent evidence has been found that graphitized irons differ materially in oxidation resistance from ungraphitized irons of similar chromium content.

47. Examination of scale on the unalloyed and alloyed cast irons has shown that the scale becomes denser as the chromium content increases. This undoubtedly contributes to the increase in oxidation resistance exhibited by chromium-bearing irons. Analysis of the scale on chromium-bearing irons shows that the ratios of chromium to iron and silicon to iron are somewhat higher in the scale than in the original irons, this effect being most marked at the 1.5 per cent and 2.0 per cent chromium levels. A concentration of chromium and silicon at the scale-metal surface of alloy steels has been reported by other investigators[4]. A similar concentration evidently occurs in alloy cast irons. The presence of chromium, however, as well as silicon, appears necessary to produce a decided concentration of silicon in the scale on cast iron.

48. The appearance and analysis of the scale were not appreciably altered by graphitizing additions.

49. The growth of cast iron has been found to be drastically decreased by chromium additions. When the chromium content reaches 1.5 per cent only very slight growth is evident after exposure for 516 hours to 1472°F. (800°C.) and at a 2.0 per cent chromium level the growth is negligible in sound specimens. The occurrence of internal shrinkage appears to increase growth at a given chromium level, and the elimination of such shrinkage by graphitizer additions in the 2.0 per cent chromium range has been noted. The graphitized irons show on the average slightly less growth than ungraphitized irons of similar chromium content.

50. The present tests have demonstrated that the degree of

oxidation and more particularly the growth of cast iron, is intimately connected with the penetration of a "metal-oxide" constituent beneath the surface of the iron. Gas analysis of representative samples has shown that this "metal-oxide" constituent actually contains a high percentage of oxygen, but does not correspond to any of the recognized iron oxides. Chromium additions are effective in inhibiting and finally preventing penetration of this "metal-oxide" constituent even in the presence of graphite flakes.

51. Metallographic examination has shown that the unalloyed base iron is gradually converted on exposure to 1472°F. (800°C.) to a ferrite plus "metal-oxide" mixture with a loss of 60 per cent of its original strength. Additions of chromium prevent the complete breakdown of cementite to graphite plus ferrite but do not prevent spheroidization of the pearlite. The presence of as little as 0.50 per cent chromium limits the strength loss to about 16 per cent, and with 1.0 per cent to 2.0 per cent chromium the change from the original strength is negligible.

52. It has been found that graphitization of 1.5 per cent and 2.0 per cent chromium irons by special alloys such as alloys 1, 2 and 3, improves the physical properties of the irons without producing any detectable sacrifice in their oxidation and growth resistance.

ACKNOWLEDGMENT

The generous aid furnished by the staff of the Union Carbide and Carbon Research Laboratories, Inc., in carrying out the investigation and of W. Crafts in reviewing the manuscript is gratefully acknowledged. The encouragement of J. H. Critchett, vice president, and A. B. Kinzel, chief metallurgist, was of material aid in the prosecution of the work.

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DISCUSSION

Presiding: S. C. MASSARI, Association of Manufacturers of Chilled Car Wheels, Chicago, Ill.

Co-Chairman: R. G. MCELWEE, Vanadium Corporation of America, Detroit, Mich.

G. P. PHILLIPS[1]: Two castings in which we have used iron of this type are heat control valves and pre-combustion chamber cups. The irons used contained slightly less than 1.0 per cent chromium, with no other alloying elements added.

The heat control valves, cast with chromium cast iron, have been used for four or five years. They are used in combination intake and exhaust manifolds to effect transfer of heat from exhaust gases to incoming gases in kerosene burning engines. Such valves cast with plain irons oxidize, scale and grow rapidly in service so that in a relatively short time the valves consist largely of iron oxide and they bind and stick in the manifolds and will not operate. The use of chromium iron overcame these troubles.

The pre-combustion chambers are small cylindrical castings that fit in diesel cylinder heads between the fuel nozzle bodies and the head walls. They are subject to high temperatures and corrosive conditions and have been made from silchrome steel forgings for years. Chromium cast iron proved entirely satisfactory in prolonged tests of around 1500 hours in this service and is much less costly.

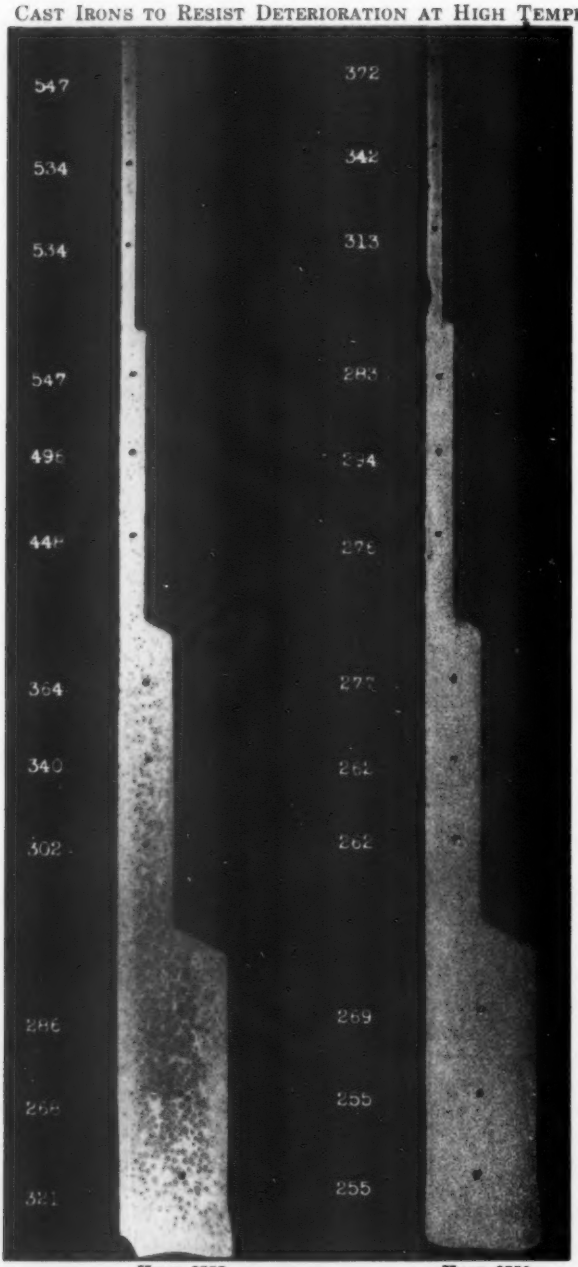
Due to restrictions on the use of chromium, neither of these two types of castings is being cast with chromium iron at present but it is our intention to use it after we have won the war.

MEMBER: Regarding the section size, how thin a casting can be made and still get the graphitized product?

MR. BURGESS: The effect of the graphitizing treatment can be detected even in ⅛-in. thick sections of the 1.5 and 2.0 per cent chromium cast irons. Figure 20 illustrates etched cross sections of step bars cast from the 1.5 per cent chromium irons 2 and 4 described in the paper. Brinell hardness readings obtained on the one-in., ½-in., ¼-in*., and ⅛-in.* steps have been superimposed on this figure. The greater structural uniformity of bar 4, graphitized with alloy 1, is at once apparent. It can also be noted that the Brinell hardness is very uniform in the first three steps of the graphitized iron and does not exceed 300 Brinell even in the ¼-in. step. In the ⅛-in. step of the same bar the Brinell hardness reaches a maximum of 375. On the other hand, bar 2, which received no graphitizing treatment, exhibits a hardness well in excess of 300 Brinell in the ½-in. step, and the full hardness of a white iron is developed in the ¼-in. and ⅛-in. steps. It is also interesting that we observed that in a single step, such as the one-in. step, the hardness of the graphitized iron 4 was approximately constant over the whole cross section, while in the same step of the ungraphitized bar 2 there was considerable mottling and the

[1] Automotive Foundry Div., International Harvester Co., Chicago, Ill.

* Brinell hardness on ¼-in. and ⅛-in. steps converted from Rockwell "C" values.



HEAT 8757
BAR 2
TREATMENT: F.G. FeCr

HEAT 8759
BAR 4
F.G. FeCr + ALLOY 1

FIG. 20—ETCHED CROSS SECTIONS OF STEP BARS CAST FROM THE 1.5 PER CENT CHROMIUM IRONS 2 AND 4 DESCRIBED IN THE PAPER.

hardness actually rose to about 460 as the outer edges of the one-in. step were approached.

The graphitizing effect was very similar to the above in the case of step bars cast from the graphitized 2 per cent chromium cast irons with the exception that a greater hardness approaching that of white iron was developed in the ⅛-in. step.

CO-CHAIRMAN MCELWEE: We did some work that confirms this. We made some cylinder blocks with as high as 2 per cent chromium and found no chilled edges. They were completely gray, quite hard, 300 Brinell or thereabouts, but had no definite evidence of chill on any pan rail or any part of the block. Also, we found excellent recovery of chrome, and we found that on a fluidity test, the spiral was reduced very slightly.

MR. VANICK [2]: Have you had a chance to match the 6 per cent silicon-silal composition as against the 2 per cent chrome? Then, can you tell us about the mechanism of spheroidization, described in paragraphs 40 and 41 and summarized in paragraph 51, explaining that additions of chromium prevent the complete breakdown of cementite to graphite but do not prevent spheroidization? Apparently spheroidization takes place under this condition of heating.

MESSRS. BURGESS and SHRUBSALL (*authors' closure*): Our thanks are due to Mr. McElwee for his confirmatory data. As regards Mr. Vanick's question on high silicon irons, it is assumed that he refers to 2 per cent chromium cast irons containing 4 to 6 per cent silicon. It is possible that the higher silicon present in such irons may further contribute to heat resistance, and tests are now under way to determine whether these higher silicon irons possess different properties from the normal silicon irons considered in the present paper.

As regards Mr. Vanick's question on spheroidization, it has been noted that although primary carbides in irons containing 1 per cent or more chromium are generally resistant to change when heated to moderate temperatures, the carbide existing as a constituent of pearlite can be spheroidized fairly readily. Although this effect can be partly explained by the normally greater tendency of small particles to spheroidize, it is so marked as to give rise to the belief that the primary and eutectoid carbides may also differ in composition. That some chromium is contained in the spheroidized pearlitic carbides, however, has been indicated by results on annealing the present irons and previous results on annealing malleable iron containing small amounts of chromium. In such malleable irons the pearlitic carbides spheroidized readily, but the spheroids did not break down completely to ferrite and graphite, as was the case in chromium-free malleable irons treated in the same manner.

[2] International Nickel Co., New York, N. Y.

Report of Steel Division Committee on Radiography

To Members of the Steel Division:

Gentlemen:

Your Radiography Committee has followed developments in the field of industrial radiography closely during the year (May 1941 to April 1942).

We believe that, because of the war effort, a number of steel foundries have used radiography for the first time this year as a routine inspection test. We also believe that the number of foundries using radiography has increased materially above the figure of 41 set forth in the radiographic questionnaire reported last year in our report.

During the year the X-ray laboratory of the (Canadian) National Research Council, Ottawa, prepared material on *"Foundry Terminology of Interest to Radiographers."* These terms have been found valuable in Canadian foundries and laboratories and they were forwarded to the American Society for Testing Materials as an aid to radiographers in this country.

Your Committee has reviewed the terminology, making certain changes which are in keeping with our terminology and radiographic policies and is presenting these terms to the Steel Division. This material will also be presented to the American Society for Testing Materials for consideration. It is suggested that the Steel Division accept the following terminology as standard methods of expression:

Group A—Types of Cavities*

Extended Dull Cavity—An extended dull cavity is free from sharp angles but drawn out so that it is more than three times as long as it is broad.

Dull Cavity—A dull cavity is one that produces on the radiograph an image that is free from acute external angles and is not more than three times as long as it is broad.

Sharp Cavity—A sharp cavity is one that produces on the radiograph an image of irregular shape, characterized by sharp angles.

* No distinction is made between empty cavities and those containing material of low (radiographic) absorption such as sand.

Group of Cavities—Distinction is made between isolated cavities and groups of cavities. A cavity is said to be isolated from other cavities when it is unlikely that a fracture through this cavity will pass through any of the other cavities. Cavities are said to form a group when a fracture is likely to pass through more than one of them.

Chain of Cavities—Chain of cavities is a number of cavities distributed along a line in and parallel to the junction between two elementary parts of a casting (*e.g.*, the junction between a web or flange and other parts of a casting).

Small Distributed Cavities—These cavities vary in size from the dimensions of the metal grains down to the limits of unaided vision and are distributed in large numbers throughout a considerable part or the whole of the casting. They produce a speckled appearance on the radiographs of thin sections. The larger cavities produce individual images on the radiograph; smaller cavities cause a mottled appearance resulting from the superposition of large numbers of tiny holes.

Spores—This term is suggested as a brief substitute for "small distributed cavities." It is derived from a Greek word meaning "to sew" (seed), *i.e.*, to distribute at random. The same root occurs in the English word "sporadic." It should be distinguished from the word "pores."

GROUP B—SHRINKAGE CAVITIES

Macroshrinkage—Large, irregular cavities in the body of the metal, particularly in heavy sections where feeding is restricted. The general shape is an open dendrite with its direction parallel to the nearest cooling surfaces.

Thick-Thin Shrinkage—Pipe form cavities at the junction of a thick with a thin section, directed along the normal to the junction line. This defect often occurs midway between heavy bosses.

Pipe Shrinkage—Roughly cylindrical cavities parallel to the direction of flow of the metal and to the cooling surfaces.

Centerline Weaknesses (*Microshrinkage or Interdendritic Piping*)—Very small cavities occurring between the individual grains and usually found on the thermal centerline of the section. The radiographic appearance will vary from a general mottling

of the film to a tree-like group of interconnected sharp cavities.

GROUP C—GAS CAVITIES

Blow-Holes—Large cavities due to gas evolved from the cooling metal or trapped in the mold. They are easily recognized by their almost spherical shape. On sectioning, evolved gas cavities have a smooth untarnished surface while trapped gas is likely to have an oxidized surface.

Pin Holes—Assemblies of very small round cavities near the surface.

Surface Holes—Isolated pipe or rounded cavities connected with the surface.

GROUP D—INCLUSIONS

Sand Inclusions—Isolated irregular appearing cavities usually very near to the surface.

Slag Inclusions—Large irregular appearing cavities elongated in the direction of flow of the metal.

GROUP E—CRACKS

Hot Tears—Cracks of a decidedly ragged nature with numerous branches. They have no definite line of continuity and may exist in groups. They may or may not terminate at the surface. Small cavities from which these tears radiate may be found associated with them.

Cracks—Fissures that are usually continuous throughout their length. They usually exist singly and terminate at the surface.

Committee E-7 of the AMERICAN SOCIETY FOR TESTING MATERIALS has not accomplished anything of interest to foundrymen during the past year. The Committee had plans for the publication of the Navy radiographic standards for gamma ray radiography but they have not been published. We have been advised, however, that a new set of standards will be issued by the Bureau of Ships in the near future.

The Bureau of Ships, Navy Department, has out a new preliminary draft on general specifications for Inspection of Material, Appendix II—Metals, Part F—Radiography, Section F-1, Defini-

tions and Radiographic Requirements, March 1, 1942.

During the year articles on radiography have appeared in various technical publications. Those that may be applicable to radiographers in the steel casting industry are listed.

An article by H. F. Kaiser[1] describes an ingenious design for a metal shipping container for radium for use in radiography. Steel, tungsten powder, mercury and plastics are used in its construction.

In a paper by Zucker and Sampson[2] there is described a portable, rugged, direct reading X-ray intensity meter that requires little maintenance and may be inexpensively constructed. Another article[3] was presented to show the use of the million-volt X-ray equipment. The more important features of the equipment are discussed.

D. M. McCutcheon[4] discusses the use of the million-volt X-ray machine on castings at the Ford Motor Company. These units produce useful X-ray radiation with applied voltages of from 5,000 to 1,000,000 volts.

An interesting article by A. J. Moses[5] presents developments and improvements of industrial X-ray apparatus. The million-volt X-ray equipment is described.

A paper presented by L. F. Curtiss[6] discusses protection of personnel handling radium. Mr. Curtiss shows photographs and explains the operation of a commercial instrument which indicates amount of gamma ray exposure. Details of the warning circuit to indicate excessive exposure are shown.

In an article by Kaiser, Friedman and Hafner[7] there is presented the minimum distance requirements in the gamma ray radiography of one and 3-in. steel sections. Various. amounts of radium are used in obtaining minimum distances.

A study was made[8] of thin intensifying screens for the purpose of obtaining duplicate X-ray radiographs of nearly equal densities in ranges of from 75 to 225 kv. Data are presented on flexible and durable metallic screens.

Respectfully submitted,

COMMITTEE ON RADIOGRAPHY

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[1] Superior numbers refer to References.

References

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Effects of Superheating, Pouring Temperatures and Microstructure on the Elastic Properties of Some Plain and Alloy Cast Irons

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Abstract

Transverse strength properties were determined on 1.2-in. diameter test bars made from three types of alloy iron heated before casting to the maximum temperatures of 1400°, 1500°, 1600° and 1700°C. (2550°, 2730°, 2910° and 3090°F.). The bars were vertically cast, bottom poured in green sand molds, at a temperature 100°, 150°, 200° or 250°C. (210°, 300°, 390°, 480°F.) above the liquidus. Total, plastic, and elastic deflection, modulus of rupture, relative moduli of elasticity, and total plastic and elastic resilience were determined and the microstructure of the test bars was examined. Comparative values of four different relative moduli of elasticity relating to the same test bars but calculated by different methods are discussed. Comparison of transverse test properties of alloy and plain cast irons is made.

Introduction

1. A knowledge of the elastic properties of cast iron is important for its use in structural parts, such as piston rings, cylinder liners, etc. The present investigation is an extension to three types of alloy cast iron of a previous study[1] of the elastic properties of three types of plain cast iron. The same procedure of melting and casting and the same methods of testing as those described in the previous paper were employed.

Scope of Investigation

2. The research consisted in making transverse test bars 1.2-in.

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1 Superior figures indicate the literature references at the end of this paper.

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in diameter and 21-in. in length and testing these for transverse strength, deflection, Brinell hardness and microstructure. A universal testing machine of the hydraulic type of 50,000 lb. capacity was used for transverse tests.

METALS USED

3. Three types of alloy cast irons were selected for this investigation: Iron "L," a nickel-molybdenum high-silicon iron; Iron "M," a nickel-molybdenum-chromium, low-manganese, medium-silicon iron; and Iron "N," a nickel-molybdenum-chromium, high-manganese, high-silicon iron. The stock pig irons *B* and *C* (Table 1), used in the previous investigation, were also employed in the present study. Stock iron *B* was employed in making heats of irons *M* and *N*, while stock iron *C* was employed for making heats of iron *L*.

Table 1

CHEMICAL ANALYSIS OF STOCK PIG IRON

Iron	*Total Carbon, percent*	*Silicon, percent*	*Manganese, percent*	*Phosphorus, percent*	*Sulphur, percent*
B	3.79	1.40	0.63	0.181	0.062
C	3.44	2.43	0.77	0.395	0.050

FOUNDRY PROCEDURE

4. The foundry technique was similar to that used in the previous investigation.

Preparation of Mold

5. Molds for transverse test bars were made of a mixture of 8 parts molding sand and 1 part sea coal, tempered to approximately 7 percent moisture. The mold cavities were faced with non-graphitic, carbonaceous material of commercial origin[2] of the following approximate analysis: Volatile matter, 4.0 per cent; Fixed carbon, 74.0 per cent; Ash, 22.0 per cent. The bars were bottom poured in groups of four in a three-part, vertical flask and each flask contained two groups, *i.e.*, eight bars.

Melting

6. Charges of 230 to 250 lb. of iron, in a commercial magnesia crucible, were melted in a high-frequency, induction furnace of the tilting type.

7. When the charge of stock iron was melted, the metal was slagged off and necessary additions were made. First, open-hearth ingot iron was charged into the melt and then other elements were added. Nickel was added in the form of nickel shot, whereas silicon, manganese, chromium and molybdenum were added in the form of their respective ferro-alloys. The major portion of the ferrosilicon (about two-thirds of the total amount) was added after all other additions had been made. The elapsed time between the last addition of ferrosilicon and the pouring of a group of transverse tests bars, varied from about 4 min. to 1 hr., depending upon the maximum heating and pouring temperatures employed.

Temperatures Used and Their Measurement

8. Each melt was heated to a predetermined maximum temperature of 1400°, 1500°, 1600°, or 1700°C. (2550°, 2730°, 2910°, or 3090°F.). Each group of four bars was cast as a unit at a predetermined pouring temperature, of 100°, 150°, 200° or 250°C. (210°, 300°, 390° or 480°F.), above the liquidus temperature of the iron investigated. Temperatures up to 1600°C. (2910°F.) were measured by a platinum to platinum-rhodium thermocouple and temperatures above 1600°C. (2910°F.) by an optical pyrometer. To determine the corrections to be applied to the readings of the optical pyrometer under these conditions, observations were taken simultaneously with both the thermocouple and the optical pyrometer in the temperature range of 1400° to 1550°C. (2550 to 2820°F.). These corrections were then plotted as a function of the temperature, and the curve extended up to 1700°C. (3090°F.). The thermocouple assembly used in measuring temperatures of molten cast iron was described in a previous paper [2].

General Remarks Concerning Composition of Transverse Test Bars

9. After completing the transverse tests, the bars were sampled for chemical analysis. The analytical data are summarized in Table 2. Since the variation in pouring temperature did not appreciably affect the composition of heats, these data refer to the heats made at different maximum heating temperatures, pouring temperature being constant.

10. The most consistent results were obtained with iron "L,"

Table 2

CHEMICAL ANALYSIS OF CAST IRON BARS OF IRONS "L," "M" AND "N," HEATED TO DIFFERENT MAXIMUM TEMPERATURES AND POURED AT 1350°C. (2460°F.)

Iron	Maximum Heating Temperature °C.	Maximum Heating Temperature °F.	Carbon			Chemical Analysis, Percent						
			Total	Graphitic	Combined	Silicon	Manganese	Phosphorus	Sulphur	Nickel	Chromium	Molybdenum
L	1400	2550	3.38	2.82	0.56	2.35	0.63	0.39	0.05	1.04	——	0.72
	1500	2730	3.33	2.79	0.54	2.34	0.70	0.39	0.05	1.05	——	0.76
	1600	2910	3.33	2.75	0.58	2.39	0.71	0.39	0.04	1.08	——	0.71
	1700	3090	3.23	2.62	0.61	2.32	0.72	0.40	0.04	1.01	——	0.75
M	1400	2550	3.16	2.43	0.73	1.84	0.43	0.14	0.03	1.57	0.27	0.98
	1500	2730	3.12	2.37	0.75	2.02	0.45	0.15	0.03	1.60	0.24	0.77
	1600	2910	3.04	2.33	0.71	2.02	0.47	0.14	0.04	1.59	0.24	0.76
	1700	3090	3.14	2.42	0.72	2.23	0.53	0.15	0.04	1.67	0.28	0.86
N	1400	2550	2.83	2.10	0.73	2.59	0.89	0.13	0.04	1.24	0.21	1.20
	1500	2730	3.06	2.46	0.60	2.76	1.04	0.13	0.04	1.27	0.21	1.09
	1600	2910	2.82	2.13	0.69	2.75	0.99	0.13	0.04	1.23	0.21	1.22
	1700	3090	2.88	2.16	0.72	2.70	0.99	0.12	0.04	1.24	0.21	1.17

whereas a considerable fluctuation in composition was noticed for irons "M" and "N," particularly in the silicon content.

DETERMINATION OF PROPERTIES

11. The term "elastic properties" in this paper connotes those complex properties that determine the behavior of cast iron under load and, more specifically, under transverse bending load.

Deflection

12. It is well known that the determination of the elastic properties of cast iron is complicated by the fact that even low stresses produce plastic as well as elastic deformation.

13. The method used by the National Bureau of Standards to measure deflection in cast iron bars has been described elsewhere[1, 3]. A brief outline for the reader's convenience is as follows: As shown in Fig. 1, a rubber band *B* is stretched tightly along the length of the bar *A* and is held in position by two clamps *C*. Metal strips on the inner surface of the clamps keep the rubber band near to, but not in contact with, the surface of the bar at all times. The 18-in. spacing between the two clamps is the same as that between the supports for the bar in the testing machine. A small piece of paper *D* is cemented to the surface of the bar midway between the clamps *C*, and the upper edge of this piece of paper serves as a reference mark.

14. In conducting the test, the bar is placed in the testing ma-

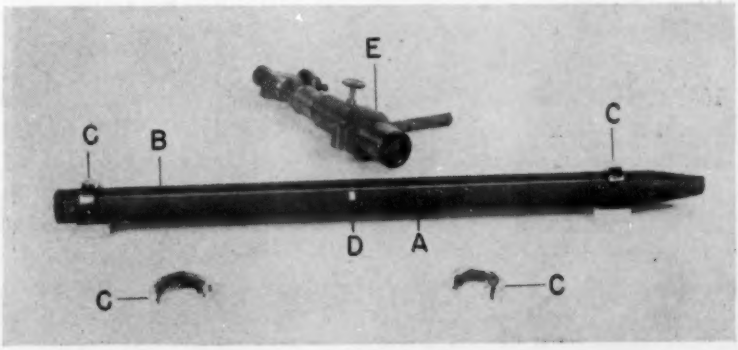

FIG. 1—APPARATUS FOR MEASURING DEFLECTION OF CAST IRON BARS UNDER TRANSVERSE LOADING. *A* — CAST IRON BAR; *B* — RUBBER BAND; *C* — CLAMPS; *D* — REFERENCE MARK; *E* — MICROMETER TELESCOPE.

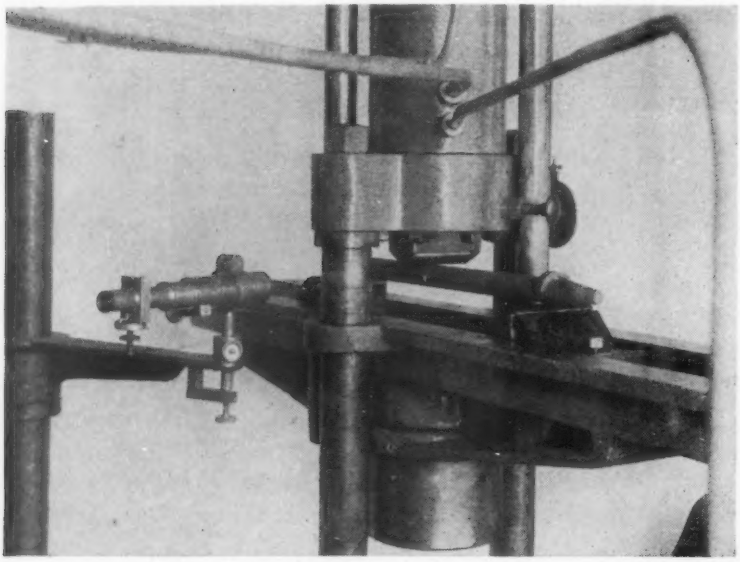

FIG. 2—TEST BAR MOUNTED IN THE 50,000 LB. TESTING MACHINE. MICROMETER-TELESCOPE SUPPORT IS INDEPENDENT OF THE TESTING MACHINE.

chine (Fig. 2) and a micrometer-telescope (E, Fig. 1) mounted at a distance of 20-in. from the bar, is used to measure the distance between the lower edge of the rubber band and the reference mark. The rubber band, clamped to the bar at the two supports, remains practically straight so that the displacement of the reference mark relative to the band is a measure of the center deflection of the loaded bar. A similar measurement after the load has been removed indicates the permanent set at the center.

15. After a test bar *A* was mounted in the testing machine and adjusted until the rubber band *B* was in the horizontal plane through the neutral axis of the bar, a load of 50 lb. was applied and the distance between the lower edge of the rubber band and the reference mark was determined and used as the zero reading. This load was sufficient to seat the bar firmly. The deflection of the bar was then measured as it was loaded in a series of steps of 100 or 200 lb. each. After the load had reached 1000 lb. each application of load was followed by unloading to the original 50 lb. load, and the permanent set in the unloaded bar was determined.

Table 3

TRANSVERSE BREAKING STRENGTH, MODULUS OF RUPTURE AND ULTIMATE, TOTAL AND ELASTIC DEFLECTIONS*

Iron	Pouring Temp.		Transverse Breaking Strength of Metal Heated to				Modulus of Rupture of Metal Heated to				Ultimate Total Deflection of Metal Heated to				Ultimate Elastic Deflection of Metal Heated to			
			1400° C.	1500° C.	1600° C.	1700° C.	1400° C.	1500° C.	1600° C.	1700° C.	1400° C.	1500° C.	1600° C.	1700° C.	1400° C.	1500° C.	1600° C.	1700° C.
	°C.	°F.	lb.	lb.	lb.	lb.	lb. per sq. in.				in.	in.	in.	in.	in.	in.	in.	in.
L	1400	2550	——	2440	2590	2640	——	64,800	68,700	69,900	—	0.22	0.24	0.22	—	0.20	0.20	0.19
	1350	2460	2630	2520	2650	2600	69,900	66,800	70,300	68,900	0.24	0.21	0.24	0.21	0.20	0.18	0.21	0.18
	1300	2370	2730	2620	2760	2830	72,300	69,600	73,100	75,000	0.24	0.22	0.26	0.22	0.21	0.19	0.21	0.18
	1250	2280	2310	2630	——	2640	61,300	69,800	——	72,700	0.22	0.21	—	0.22	0.19	0.19	—	0.19
M	1450	2640	——	3390	3030	2980	——	89,900	80,400	78,900	—	0.36	0.30	0.31	—	0.26	0.23	0.23
	1400	2550	3190	3180	3250	3111	84,600	84,500	86,200	82,000	0.32	0.31	0.33	0.31	0.24	0.24	0.24	0.23
	1350	2460	3350	3140	3470	3290	88,900	83,200	92,100	87,200	0.34	0.30	0.36	0.33	0.24	0.23	0.26	0.25
	1300	2370	3430	3360	3140	3220	91,100	89,200	83,300	85,500	0.32	0.35	0.33	0.31	0.24	0.26	0.24	0.24
	1250	2280	3340	——	——	——	88,800	——	——	——	0.34	—	—	—	0.24	—	—	—
N	1450	2640	——	3200	3500	3420	——	85,000	92,900	90,800	—	0.31	0.33	0.30	—	0.24	0.25	0.23
	1400	2550	3400	3290	3690	3520	90,200	87,300	97,800	91,600	0.32	0.31	0.34	0.30	0.24	0.25	0.26	0.23
	1350	2460	3510	3430	4060	4030	93,200	91,100	107,700	106,900	0.32	0.33	0.37	0.34	0.24	0.25	0.28	0.27
	1300	2370	3550	3610	3960	3720	94,100	95,800	105,200	98,700	0.32	0.33	0.37	0.33	0.25	0.26	0.28	0.25

*The values presented in this table are averages of values for a group of four bars cast at the same pouring temperature.

16. The total deflection at the breaking load and the "set" of each bar under increasing step loadings were determined and the elastic deflection was taken as the difference between the total and the plastic deflection for each load. In each group of four bars (poured at the same temperature), two were tested by the step loading and unloading method while the two companion bars were progressively loaded to failure, without unloading between successive loads. No difference in the breaking loads and the load-deflection curves, which could be ascribed to the mode of loading, was observed.

17. As shown in Table 3, there is no definite relation between the ultimate total, as well as ultimate elastic deflections, and maximum heating and pouring temperatures. The ultimate total, elastic and plastic deflections are considerably higher for irons "M" and "N" than for iron "L." From Table 3 and the data obtained in the previous investigation, it may be noted that the ultimate total, elastic and plastic deflections for plain irons (irons "A," "B," and "C") and alloy irons (irons "L," "M," and "N") range as shown in Table 4.

Table 4

ULTIMATE DEFLECTIONS AND PROPORTION OF PLASTIC DEFLECTION TO TOTAL DEFLECTION AT FRACTURE FOR ALLOY AND PLAIN CAST IRONS

	Alloy Irons			Plain Irons		
	L	M	N	A*	B*	C*
	Ultimate Deflection, in.					
Total	0.21-0.26	0.30-0.36	0.30-0.37	0.18-0.24	0.25-0.30	0.20-0.28
Elastic	0.18-0.21	0.23-0.26	0.23-0.28	0.15-0.18	0.17-0.19	0.16-0.21
Plastic	0.02-0.05	0.07-0.10	0.07-0.09	0.03-0.06	0.08-0.11	0.04-0.07
Proportion of Plastic Deflection to Total Deflection at Fracture, percent						
	9 to 19	23 to 28	23 to 24	17.0 to 25.0	32.0 to .37	20.0 to 25.0

18. Table 4 indicates that the ultimate elastic deflections obtained for alloy iron "L" are practically equivalent to those of plain irons "A," "B," and "C." However, the total plastic deflection of alloy iron "L" was somewhat inferior to those of the

* Iron "A" contains: Total Carbon, 3.44 percent; Silicon, 1.40 percent; Manganese, 0.15 percent; phosphorus, 0.46 percent; Sulphur, 0.02 percent. Chemical analyses of irons "B" and "C" are given in Table 1.

plain irons "B" and "C." The highest values of total and elastic deflections were observed for alloy irons "M" and "N," whereas the highest values of plastic deflection were associated with plain iron "B." If the proportion of plastic deflection to the total deflection at fracture is considered as an index of rigidity of cast iron, then iron "L" is the most rigid and iron "B" the least rigid. The rigidities of irons "M," "N," "A," and "C" are almost equal.

19. All the results of this investigation confirm the conclusions drawn from the previous study[1] with regard to the total, plastic and elastic deflection curves obtained by the method just described, *i.e.*, the total and plastic deflection curves are continuous curves inclining progressively toward the deflection axis. The elastic-deflection curve is a straight line in its lower portion, but at approximately 3/5 of the breaking load, it inclines toward the deflection axis. Typical load-deflection curves for the irons investigated are shown in Fig. 3.

20. All transverse tests were made with a universal testing machine of the hydraulic type of 50,000 lb. capacity, the rate of loading corresponding to 0.12-in. per min. travel of the free cross-head of the testing machine. According to an A. S. T. M. specification*,

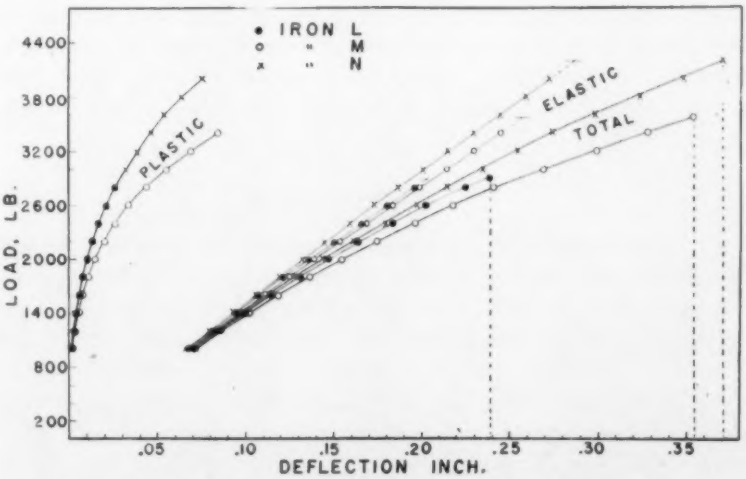

FIG. 3—TYPICAL PLASTIC, ELASTIC AND TOTAL-DEFLECTION CURVES OF IRONS "L," "M," AND "N."

* American Society for Testing Materials Specification E4-36, 1939 Book of Standards, part 1, page 774.

the error for loads within the loading range of a testing machine shall not exceed 1 percent. Since the error of the machine for loads smaller than 1000 lb. exceeds 1 percent, only the total deflections were measured at the loads of 400, 600, 800, 1000 lb., etc. and no plastic and elastic deflections were determined at loads less than 1000 lb. Consequently, curves corresponding to the loads below 1000 lb. are not shown in Fig. 3. It may be stated, however, that in most of the cases observed, the initial portions of the load-total deflection diagrams (for loads of 200 to 1000 lb.) appeared to be continuous, smooth curves. This was particularly true of the alloy irons.

TRANSVERSE STRENGTH

21. It may be noted in Table 3 that the transverse breaking strengths for iron "L" range from 2310 to 2830 lb., iron "M" from 2980 to 3470 lb., and iron "N" from 3200 to 4060 lb. In accordance with A. S. T. M. classification*, these irons would fall in the following classes: Iron "L," 35-40; iron "M," 50; and iron "N," 50-60 or higher.

22. The higher strength of irons "M" and "N," as compared with iron "L," probably is due to their higher nickel content and more particularly to the presence of chromium. The low-carbon, high manganese and molybdenum contents of iron "N" appear to account for the higher strength as compared to iron "M." This high strength was obtained in spite of the higher silicon content present in iron "N."

MODULUS OF RUPTURE

23. As shown in Fig. 4, the maximum heating temperature had no effect on the modulus of rupture of irons "L" and "M," but the modulus of iron "N" was found to be somewhat higher for the maximum heating temperature of 1600° and 1700°C. (2910° and 3090° F.), than for 1400° and 1500°C. (2550° and 2730° F.). In general, however, lower pouring temperatures ranging from 100° to 150°C. above the liquidus tend to produce stronger irons.

24. It is very probable that the effect of maximum heating temperature on the physical properties of these irons was, to a certain

* American Society for Testing Materials Specifications A 48-36, A. S. T. M. Book of Standards, 1939, part 1, pp. 482-483.

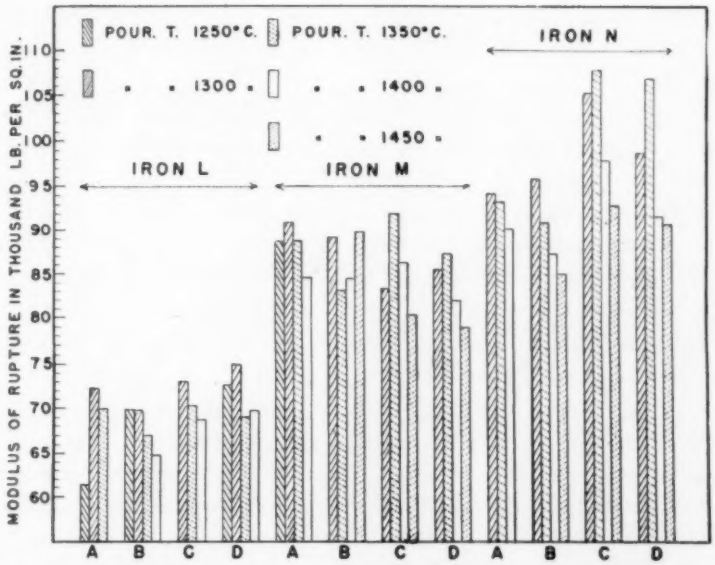

FIG. 4—EFFECT OF MAXIMUM HEATING AND POURING TEMPERATURES ON THE MODULUS OF RUPTURE OF IRONS "L," "M," AND "N." *A* — MAXIMUM HEATING TEMPERATURE 1400°C. (2550°F.); *B* — MAXIMUM HEATING TEMPERATURE 1500°C. (2730°F.); *C* — MAXIMUM HEATING TEMPERATURE 1600°C. (2910°F.); *D* — MAXIMUM HEATING TEMPERATURE 1700 °C. (3090°F.).

degree, masked by the variation in chemical analysis and the time of making the last addition of silicon to the melt before pouring.

25. In comparing the transverse strength of alloy irons with those of plain irons "A," "B," and "C," previously studied, it may be stated that the strongest plain iron "A" is equivalent to the nickel-molybdenum iron "L." The beneficial effect of increasing the maximum heating temperature on the transverse strength was more pronounced for plain irons than for alloy irons.

26. The effect of pouring temperature for both types of iron was about the same, *i.e.*, transverse strength tended to increase with a decrease of pouring temperature.

RELATIVE MODULUS OF ELASTICITY

27. In the American Foundrymen's Association *Cast Metals Handbook*, the term "modulus of elasticity," as applied to gray iron, generally means the relative stiffness of the iron under the particular conditions of loading. In the previous and in this investigation, the term "relative modulus of elasticity" is used in

place of "modulus of elasticity." Different relative moduli of elasticity were calculated from the data obtained in this investigation:

E_1—Relative modulus computed by simple beam theory from slope of straight line through elastic load-deflection curve at 1200 lb.

$E_1(S)$—Relative modulus computed from slope of secant to load-total deflection curve at 1200 lb.

E_2—Relative modulus computed from slope of secant through elastic load-deflection curve at failure.

$E_2(S)$—Relative modulus computed from slope of secant to load-total deflection curve at failure.

28. The average values of different moduli of elasticity of irons "L," "M," and "N" obtained at different maximum heating and pouring temperatures are given in Table 5. In order to compare the different moduli of elasticity, values corresponding to 1350°C. (2460°F.) pouring temperature are plotted for different maximum heating temperatures (Fig. 5).

29. From the figures, it may be observed that the relative moduli of elasticity are arranged according to their numerical values in the following order: the values for E_1 are the highest and for $E_2(S)$ the lowest; E_2 and $E_1(S)$ values are comparatively close

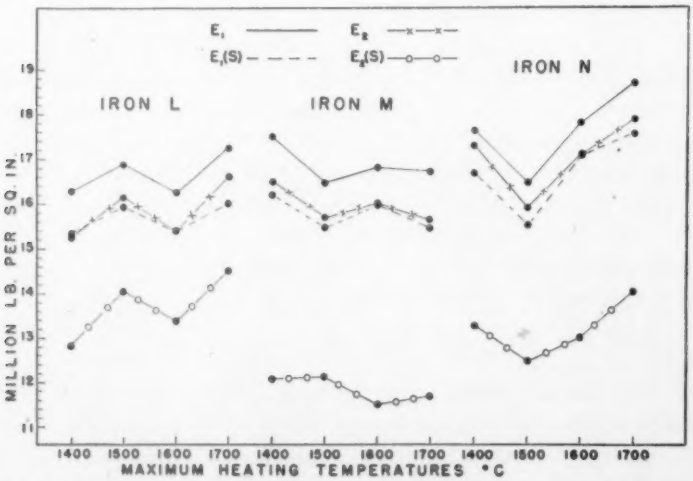

FIG. 5—COMPARATIVE VALUES OF MODULI OF ELASTICITY OF IRONS "L," "M," AND "N" CALCULATED BY DIFFERENT METHODS.

Table 5
RELATIVE MODULI OF ELASTICITY*

Iron	Pouring Temp.		Modulus of Elasticity, E_1 at Load of 1200 lb., of Metal Heated to				Secant Modulus of Elasticity at Load of 1200 lb., E_1 (S), for Metal Heated to				Ultimate Modulus of Elasticity, E_2, for Metal Heated to				Ultimate Secant Modulus of Elasticity, E_2 (S), for Metal Heated to			
			1400° C.	1500° C.	1600° C.	1700° C.	1400° C.	1500° C.	1600° C.	1700° C.	1400° C.	1500° C.	1600° C.	1700° C.	1400° C.	1500° C.	1600° C.	1700° C.
	°C.	°F.	lb. per sq. in. x 10⁶				lb. per sq. in. x 10⁶				lb. per sq. in. x 10⁶				lb. per sq. in. x 10⁶			
L	1400	2550	——	16.25	15.85	17.68	——	15.14	14.81	16.54	——	14.92	15.14	16.71	——	12.76	13.06	14.27
	1350	2460	16.27	16.90	16.24	17.25	15.35	15.91	15.41	16.00	15.26	16.13	15.39	16.62	12.83	14.05	13.39	14.51
	1300	2370	16.56	17.40	16.15	17.55	15.61	16.29	15.19	16.54	15.49	16.12	15.15	16.57	13.00	14.18	12.92	14.47
	1250	2280	16.80	17.81	——	18.00	15.86	16.39	——	16.97	15.35	16.83	——	17.00	12.68	14.67	——	14.77
M	1450	2640	——	16.65	16.91	15.89	——	15.52	16.02	14.60	——	15.74	16.09	15.49	——	11.28	12.27	11.67
	1400	2550	16.81	16.82	17.08	16.46	15.61	15.66	15.89	15.37	15.98	15.84	16.49	15.52	12.03	11.66	11.97	11.94
	1350	2460	17.50	16.48	16.82	16.72	16.20	15.45	15.99	15.47	16.51	15.71	16.01	15.67	12.08	12.13	11.52	11.71
	1300	2370	17.45	——	16.60	17.08	16.54	15.40	15.57	16.03	16.52	15.36	15.83	16.23	12.05	11.32	11.79	12.37
	1250	2280	17.54	——	——	——	16.79	——	——	——	16.69	——	——	——	12.07	——	——	——
N	1450	2640	——	16.29	17.27	17.63	——	15.12	16.19	16.97	——	15.95	16.36	17.37	——	12.77	12.92	13.83
	1400	2550	17.62	16.41	17.15	18.03	16.30	15.28	16.38	16.80	16.59	15.91	16.82	17.71	12.94	12.46	13.16	14.31
	1350	2460	17.64	16.46	17.81	18.74	16.70	15.52	17.11	17.55	17.30	15.91	17.09	17.87	13.29	12.48	13.01	14.03
	1300	2370	17.99	17.41	17.93	18.36	16.96	16.23	16.61	17.09	17.26	16.69	17.15	17.52	13.37	13.03	12.92	13.65

* The values presented in this table are averages of values for a group of four bars cast at the same pouring temperature.

together. In general, there is a small difference between E_1, E_2 and $E_1(S)$ values, but $E_2(S)$ is considerably lower. When a similar plotting is made for four different moduli of elasticity of the plain irons "A," "B," and "C," previously investigated, the results obtained are similar to those just described for the alloy irons.

30. As has been mentioned, in the determination of the relative moduli of elasticity E_1 and E_2, it is necessary to define complete load deflection curves by means of step-wise loading and unloading. This is a rather tedious procedure and requires a great deal of time. It was thought, therefore, that the determination of the relative modulus of elasticity would be simplified if a definite relation could be established between the relative modulus of elasticity E_1 and relative secant modulus of elasticity $E_1(S)$ computed for the same load. With this thought in mind, calculations were made to determine the ratios between moduli E_1 and $E_1(S)$ for all transverse test bars investigated, the load of 1200 lb. being adopted as a minimum load for these calculations. The data obtained indicate that the $\frac{E_1}{E_1(S)}$ ratios were around 1.060.

31. It seems, therefore, that for practical purposes for the irons investigated, it may be assumed that

$$E_1 = E_1(S) \times 1.060.$$

It has been found, however, that this assumption can be applied only to the group of alloy irons under present study. When similar calculations were made for the plain irons "A," "B," and "C," previously reported, it was observed that the $\frac{E_1}{E_1(S)}$ ratios were quite different and extremely irregular.

32. In Fig. 6 these ratios are plotted for the transverse test bars of both plain and alloy irons against moduli E_1. It may be seen that most $\frac{E_1}{E_1(S)}$ ratios of alloy irons approach very close to the value 1.060, whereas the same ratios applied to plain irons give widely scattered values. It already has been mentioned that for the testing machine used in this and previous investigations, the initial portion (for loads less than 1000 lb.) of the load-total deflection diagram cannot be regarded as accurate. On the other hand, the statement has been made that actually these initial portions of most diagrams appeared to be continuous smooth curves.

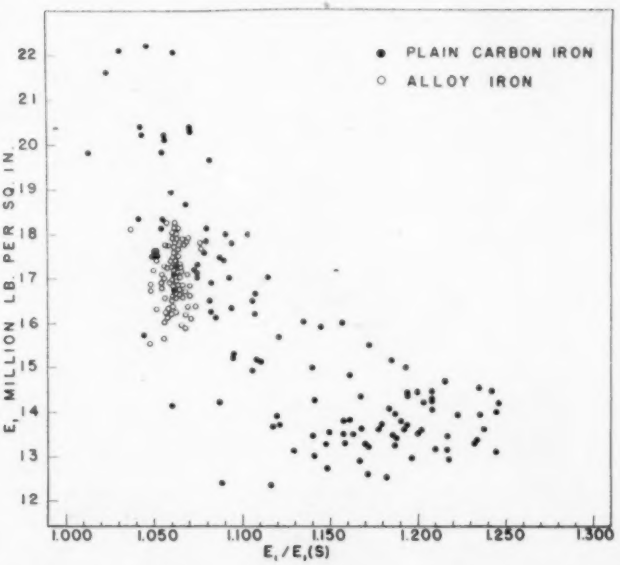

FIG. 6—RELATION OF $E_1/E_1(S)$ AND RELATIVE MODULUS OF ELASTICITY, E_1, FOR PLAIN AND ALLOY CAST IRONS.

In view of this fact it was thought that an approximate relationship can probably be obtained between the initial slope of these curves and the modulus E, if the tangent of angle a, at which the initial portion of the load-total deflection curve is inclined at its origin towards the deflection axis, is plotted* against modulus E_1. Thus, the angles a of the continuous, smooth curves obtained for the transverse test bars of plain and alloy irons were measured by means of a protractor and tangents of these angles were plotted against moduli E_1 (Fig. 7).

33. The highest values of E_1 were obtained with iron "N" heated to a maximum temperature of 1700°C. (3090°F.), but in general (Fig. 8), no definite relation was established between E_1 and the maximum heating temperature, whereas for the plain irons, there was a tendency for the values of E_1 to increase with increasing maximum heating temperature.

34. Effect of pouring temperature was practically the same for both alloy and plain irons, *i.e.*, usually there was a decrease in E_1

* Method of plotting adopted after Professor Carl Benedicks, *"Om de fasta ioeningarnas elasticitet,"* JERNKONTORETS ANNALER, vol. 124, p. 225 (1940). Also the elastic modulus of solid solutions, THE METALLURGIST, June 27, 1941, p. 20.

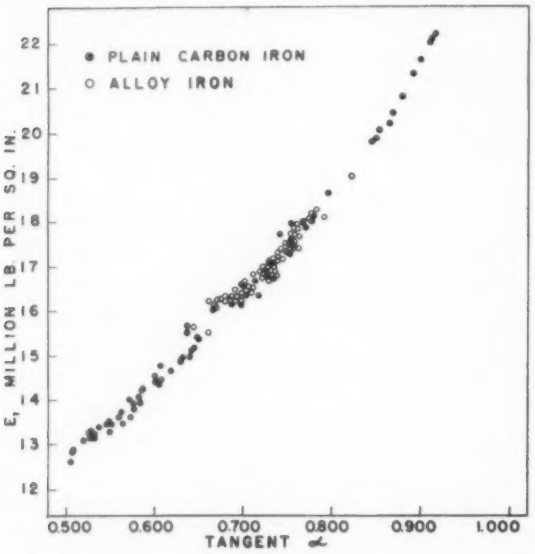

FIG. 7—RELATION OF TANGENT α TO RELATIVE MODULUS OF ELASTICITY, E_1, FOR PLAIN AND ALLOY CAST IRONS.

values with increase in pouring temperatures. When comparing the moduli E_1 of alloy irons "L," "M," and "N" with those of plain irons, it may be noted that moduli E_1 of alloy irons correspond to those of plain iron "A," heated to the maximum temperatures of 1400°, 1500°, and 1600°C. (2550°, 2730° and 2910°F.). However, the moduli of alloy irons are lower than moduli of iron "A" heated to maximum temperature of 1700°C. (3090°F.).

RESILIENCE

35. In agreement with common practice for cast iron, the term "resilience" is used in this paper to denote the work done in loading the specimen. The following resilience values are discussed:

W_1—Ultimate total resilience obtained by measuring planimetrically the area below the load-total deflection curve and between the origin and the ordinate drawn to the deflection curve at the point of rupture.

W_2—Ultimate triangular resilience, represented by a triangular area below a straight line drawn from the origin and the point of rupture on the load-total deflection curve. It is obvious that triangular resilience only approximates the true resilience and the

degree of approximation decreases as the curvature of the load-total deflection curve increases.

W_3—Ultimate elastic resilience was determined by calculating the triangular area below the ultimate-elastic-deflection curve on the assumption that this curve is a straight line. In view of the fact that ultimate-elastic-deflection curves deviate but slightly from a straight line, this assumption is permissible.

W_4—Ultimate plastic resilience. These resilience values were obtained by subtracting W_3 values from those of W_1.

36. The average values of W_1 and W_4, as well as the ratios of $\frac{W_4}{W_1}$ expressed in percentage of W_1, for each group of bars cast at the same pouring temperature, are shown in Table 6. This table indicates that all these values are considerably lower for iron "L" than for irons "M" and "N." The ultimate total resilience values range as follows: for iron "L," from 304 to 385 in.-lb.; iron "M," from 492 to 722 in.-lb.; and iron "N," 510 to 880 in.-lb.

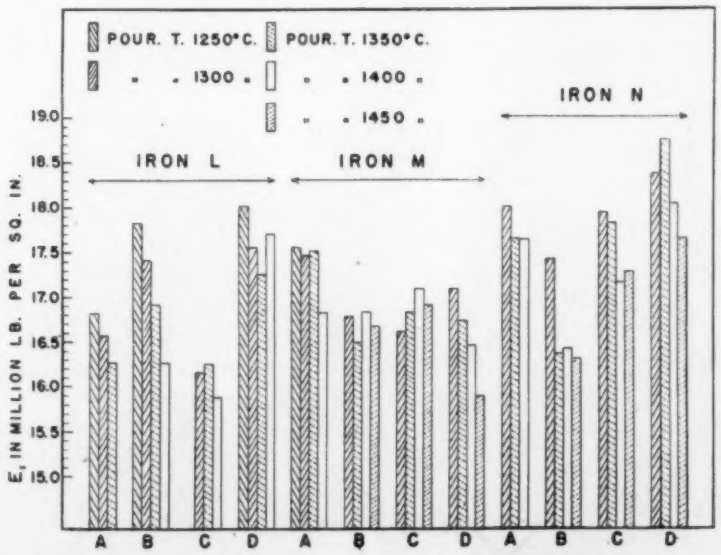

FIG. 8—EFFECT OF MAXIMUM HEATING AND POURING TEMPERATURE ON THE RELATIVE MODULUS OF ELASTICITY OF IRONS "L," "M," AND "N." *A* — MAXIMUM HEATING TEMPERATURE 1400°C. (2550°F.); *B* — MAXIMUM HEATING TEMPERATURE 1500°C. (2730°F.); *C* — MAXIMUM HEATING TEMPERATURE 1600°C. (2910°F.); *D* — MAXIMUM HEATING TEMPERATURE 1700°C. (3090°F.).

Table 6

RESILIENCE VALUES*

Maximum Heat Temp.—°C.			1400			1500			1600			1700		
Iron	Pouring Temp. °C.	Pouring Temp. °F.	Ultimate Total Res., W_1 in.-lb.	Ultimate Plastic Res., W_4 in.-lb.	Ratio, $\frac{W_4}{W_1}$ Percent	Ultimate Total Res., W_1 in.-lb.	Ultimate Plastic Res., W_4 in.-lb.	Ratio, $\frac{W_4}{W_1}$ Percent	Ultimate Total Res., W_1 in.-lb.	Ultimate Plastic Res., W_4 in.-lb.	Ratio, $\frac{W_4}{W_1}$ Percent	Ultimate Total Res., W_1 in.-lb.	Ultimate Plastic Res., W_4 in.-lb.	Ratio, $\frac{W_4}{W_1}$ Percent
L	1400	2550	—	—	——	341	73	21.41	311	56	18.00	335	70	20.90
	1350	2460	363	86	23.69	—	—	——	332	61	18.37	304	52	17.11
	1300	2370	379	89	23.48	328	67	20.43	385	81	21.04	372	75	20.16
	1250	2280	319	81	25.39	305	60	19.67	—	—	——	334	67	20.06
M	1450	2640	—	—	——	706	265	37.54	533	174	32.65	492	161	32.72
	1400	2550	581	191	32.87	603	217	35.99	612	215	35.13	528	167	31.63
	1350	2460	640	230	35.94	—	—	——	722	268	37.12	669	240	35.87
	1300	2370	659	242	36.72	692	253	36.56	557	190	34.11	592	198	33.45
	1250	2280	637	232	36.42	—	—	——	—	—	——	—	—	——
N	1450	2640	—	—	——	510	131	25.69	644	189	29.35	581	153	26.33
	1400	2550	617	186	30.15	568	153	26.94	665	189	28.42	533	134	25.14
	1350	2460	619	189	30.53	608	168	27.63	880	277	31.48	751	205	27.30
	1300	2370	658	204	31.00	661	194	29.35	799	250	31.29	672	198	29.46

*Average values for each group of bars cast at the same pouring temperature.

37. When drawing a comparison between alloy and plain irons, it may be observed that plain iron "A," which showed total resilience values from 220 to 375 in.-lb., approaches alloy iron "L." Neither maximum heating nor pouring temperatures seem to have a considerable influence on these properties for irons "L" and "M." However, a considerable improvement in these properties was observed for iron "N" when a lower range of pouring temperatures (1300-1350°C. or 2370°-2460°F.) was employed. When comparing all bars tested in this investigation, it may be noticed that iron "N" heated to the maximum temperature of 1600°C. (2910°F.) and cast at pouring temperatures ranging from 1300° to 1350°C. (2370° to 2460°F.) possessed the highest values of W_1 and W_4.

38. In connection with this observation, it may be recalled that for plain irons the effect of maximum heating and pouring temperatures was observed only for iron "A," in which case there was a pronounced decrease in resilience with increasing pouring temperatures. An increase in resilience with increasing maximum heating temperature was particularly evident in the bars of that iron poured at 1350°C. (2460°F.).

39. According to data compiled by Tucker,[4] neither the breaking load, deflection, nor resilience values gave reliable indications of the resistance to thermal shock, but the plastic resilience, expressed in percentage of the total resilience, furnished a measure of the relative toughness of his irons. From this viewpoint, irons "M" and "N" should be more resistant to thermal shock than iron "L." None of these irons, however, is superior in this respect to the plain irons, previously examined. Actually all of them are inferior to a medium cylinder iron "B," whose plastic to total resilience ratios ranged from 42 to 49 percent.

40. It is well known that silicon has a great effect on the physical properties of cast iron in general. In his work on the influence of phosphorus on iron, MacKenzie[5] plotted the ultimate total deflection values against the carbon content plus one-fourth of the silicon content and found that there was an increase of deflection with an increase of C + Si/4 values. His diagram indicated that deflection depends more on C + Si/4 values than on phosphorus content[6].

41. An attempt was made by the present writers in their previous paper[1] to find whether a corresponding relation to C + Si/4 content may be shown for the ultimate total resilience values. Al-

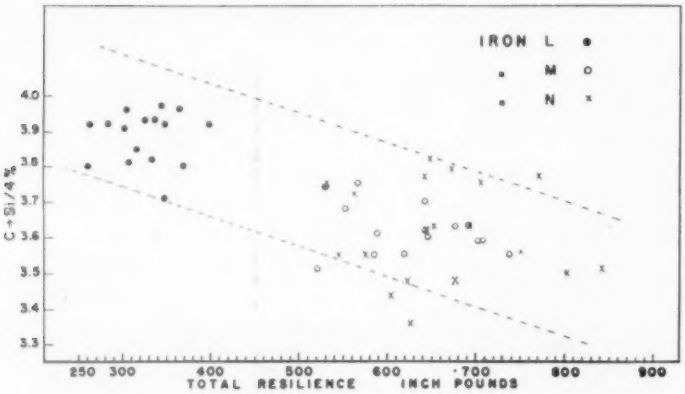

FIG. 9—RELATION OF TOTAL RESILIENCE TO CARBON AND SILICON CONTENTS.

though a probable trend of the plotted points was outlined, it was found that the results obtained did not warrant any definite conclusion.

42. In the present investigation the values C + Si/4 for irons "L," "M," and "N" were plotted against W_1, W_3 and W_4. Although the plotted points are widely scattered, nevertheless, as may be seen in Fig. 9, there is a definite trend for the ultimate total resilience to increase with a decrease of C + Si/4 values. A similar relation has been found for the ultimate plastic and elastic resiliences.

43. Another interesting relation for the resilience values has been demonstrated by MacKenzie[7] for 1.2 by 18-in. bars tested transversely. The ratios of true resilience to triangular resilience were compared with ratios of modulus of elasticity at ½ load to ultimate modulus of elasticity. He showed that these ratios, when plotted on a logarithmic scale, were almost directly proportional to each other. It should be noted that in MacKenzie's experiments both modulus of elasticity at ½ load and ultimate modulus of elasticity were "secant moduli."

44. In the present investigation, the ratios $\frac{E_1(S)}{E_2(S)}$ were plotted (Fig. 10) against ratios $\frac{W_1}{W_2}$ on linear scale; this gives roughly the same distribution of the points as a logarithmic plot since the coordinates of the points are not far different from unity. Since E_2 is nearly equal to $E_1(S)$ (Fig. 5) nearly the same relation was

obtained for the ratios $\frac{E_1(S)}{E_2(S)}$ and $\frac{E_2}{E_2(S)}$. Both $\frac{E_1(S)}{E_2(S)}$ (Fig. 10) and $\frac{E_2}{E_2(S)}$ tended to increase with increasing values of $\frac{W_1}{W_2}$.

HARDNESS

45. Brinell hardness numbers were determined on discs ¾-in. thick, cut from the tested transverse bars adjacent to the fracture. Three impressions were made on each disc; one near the center and two at points midway between the center and periphery. Two diameters were measured for each indentation and the average of these six readings was used as the hardness number of a given specimen.

46. The Brinell numbers for the irons examined were as follows:

Iron "L," 217 to 255.
Iron "M," 255 to 269.
Iron "N," 302 to 341.

47. No consistent relation was observed between the Brinell number and the transverse strength, maximum heating or pouring temperatures.

MICROSCOPIC EXAMINATION

48. After the hardness was determined on one side of a disc,

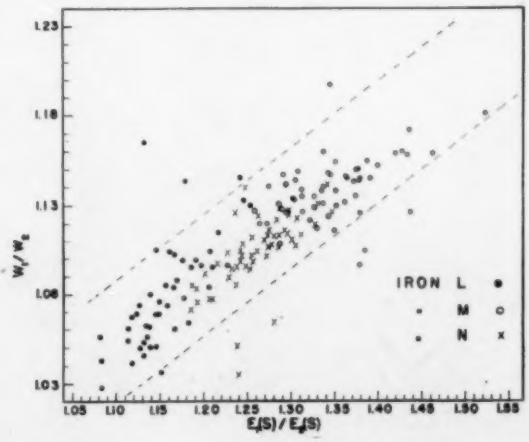

FIG. 10—RELATION OF $\frac{E_1(S)}{E_2(S)}$ TO $\frac{W_1}{W_2}$

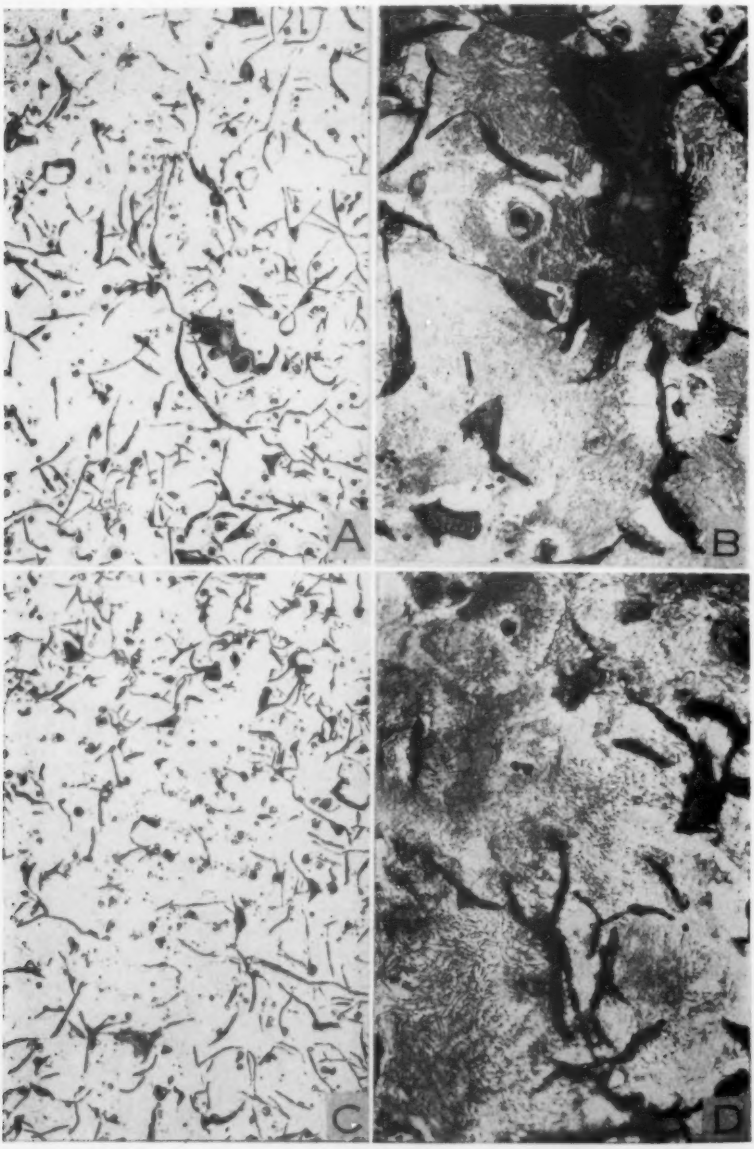

FIG. 11—IRON "L"—MAXIMUM TEMPERATURE FOR "A" AND "B"—1500°C. (2730°F.); "C" AND "D," 1700°C. (3090°F.). POURING TEMPERATURE FOR "A" AND "B," 1400°C. (2550°F.); "C" AND "D," 1300°C. (2370°F.). MODULUS OF RUPTURE FOR "A" AND "B," 61,000 LB. PER SQ. IN.; "C" AND "D," 76,000 LB. PER SQ. IN. $E_1 = 16.0 \times 10^6$ LB. PER SQ. IN. FOR "A" AND "B" AND 17.7×10^6 LB. PER SQ. IN. FOR "C" AND "D." BRINELL HARDNESS NUMBERS FOR "A" AND "B," 229; "C" AND "D," 241. "A" AND "C," UNETCHED MAGNIFICATION, x100; "B" AND "D," UNETCHED MAGNIFICATION, x500.

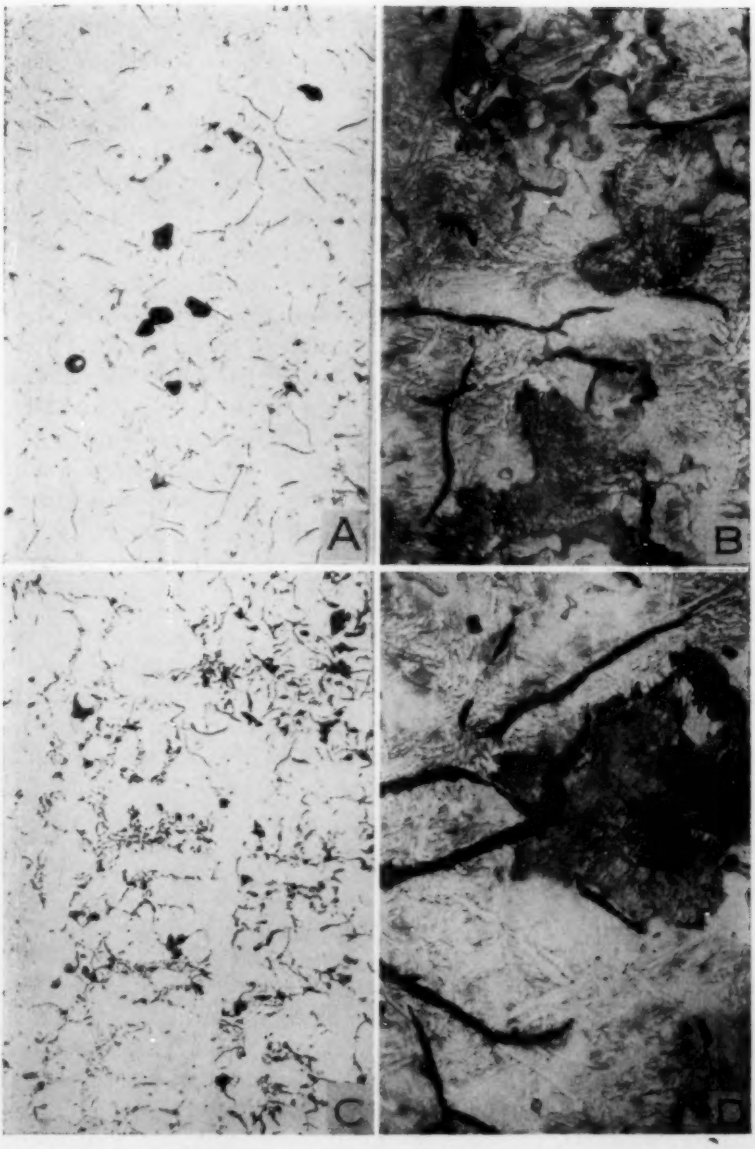

FIG. 12—IRON "M"—MAXIMUM TEMPERATURE FOR "A" AND "B," 1500°C. (2730°F.); "C" AND "D," 1600°C. (2910°F.). POURING TEMPERATURE FOR "A," "B," "C" AND "D," 1350°C. (2460°F.). MODULUS OF RUPTURE FOR "A" AND "B," 78,000 LB. PER SQ. IN.; "C" AND "D," 93,000 LB. PER SQ. IN. $E_1 = 16.0 \times 10^6$ LB. PER SQ. IN. FOR "A" AND "B" AND 17.0×10^6 LB. PER SQ. IN. FOR "C" AND "D." BRINELL HARDNESS NUMBER FOR "A," "B," "C" AND "D," 255. "A" AND "C," UNETCHED MAGNIFICATION, x100; "B" AND "D," ETCHED MAGNIFICATION, x500.

the opposite side (adjacent to the fracture) was ground, lapped on a lead-tin plate charged with fine emery, further lapped on a second plate charged with finer emery, and finally polished with an aqueous suspension of rouge, in an automatic polishing machine. Before final etching, the specimens were subjected to alternate polishing and etching operations. All specimens were examined microscopically as polished and as etched with 1 percent solution of nitric acid in ethyl alcohol. The micrographs described below represent typical structures of the irons.

49. Figure 11 indicates that, of two transverse bars of iron "L," the bar possessing greater strength and hardness shows somewhat less ferrite, finer graphite and more pronounced dendrites. The total and combined carbon contents for the stronger bars were 3.24 and 0.60 percent, respectively, and for the companion bar 3.34 and 0.56 percent. Molybdenum and nickel contents were around 0.75 and 1.05 percent, respectively. The austenite-pearlite transformation has not been suppressed. Both bars were poured at low temperatures. It is evident, therefore, that the difference observed in this case is an effect of the maximum heating temperature.

50. Figure 12 represents iron "M." Here again, the finer graphite and more pronounced dendritic structures were associated with greater transverse strength. When etched and examined at lower magnification, this specimen exhibits long dendrites extending in a radial direction almost to the center of the specimen, the dendrites of the companion specimen being much shorter and less in number. The matrix of these specimens consists of coarse pearlite and the so-called "acicular structure" with islands of fine pearlite.

51. It has been shown by various investigators[8, 9, 10] that an addition of molybdenum to cast iron reduces the rate of transformation of austenite and causes the appearance of a peculiar "acicular" structure. This structure has been called acicular pearlite, acicular troostite or acicular ferrite. It may be also called "pseudomartensite." In subsequent discussion, this structure for convenience will be designated as "acicular" structure. Two inclusions (Fig. 12D), presumably "manganese sulphide," apparently served as nuclei of the graphite formations within fine pearlite areas.

52. In spite of a rather small difference between the mechanical properties of two transverse test bars of iron "N," a considerable

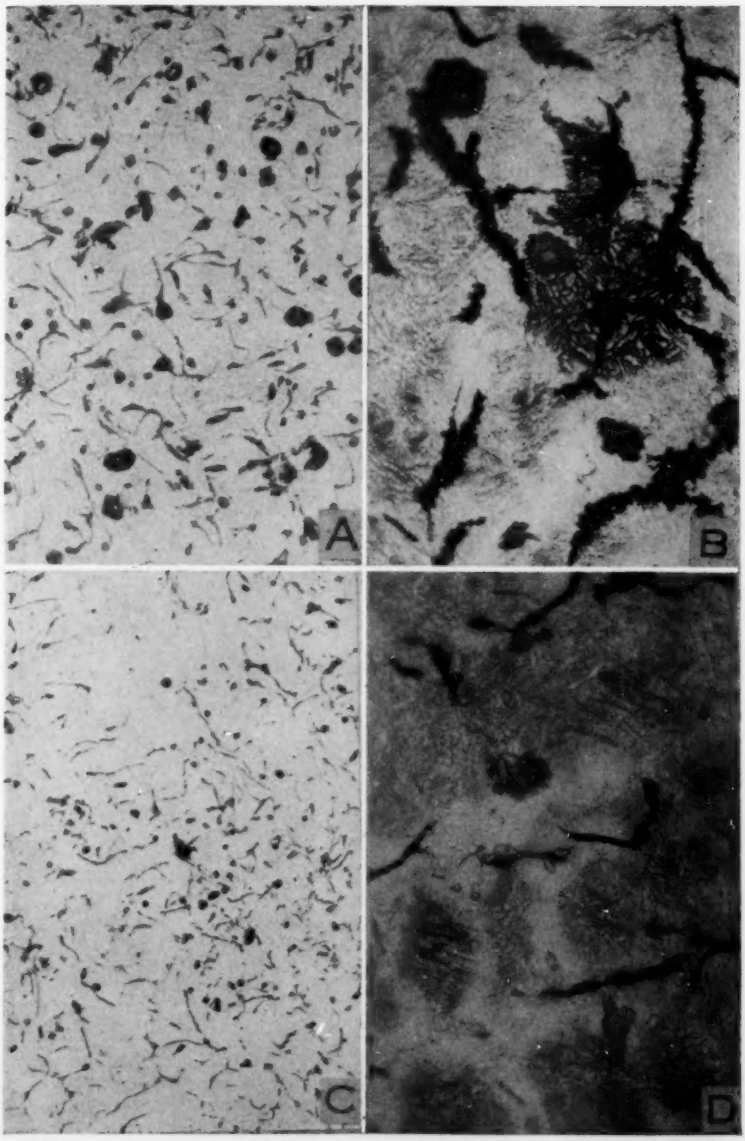

FIG. 13—IRON "N"—MAXIMUM TEMPERATURE, 1400°C. (2550°F.). POURING TEMPERATURE FOR "A" AND "B," 1400°C. (2550°F.); "C" AND "D," 1350°C. (2460°F.). MODULUS OF RUPTURE FOR "A" AND "B," 86,400 LB. PER SQ. IN.; "C" AND "D," 99,300 LB. PER SQ. IN. $E_1 =$ 17.9x10⁶ LB. PER SQ. IN. FOR "A" AND "B" AND 17.6x10⁶ LB. PER SQ. IN. FOR "C" AND "D," BRINELL HARDNESS NUMBERS FOR "A" AND "B," 311; "C" AND "D," 302. "A" AND "C," UNETCHED MAGNIFICATION, x100; "B" AND "D," ETCHED MAGNIFICATION, x500.

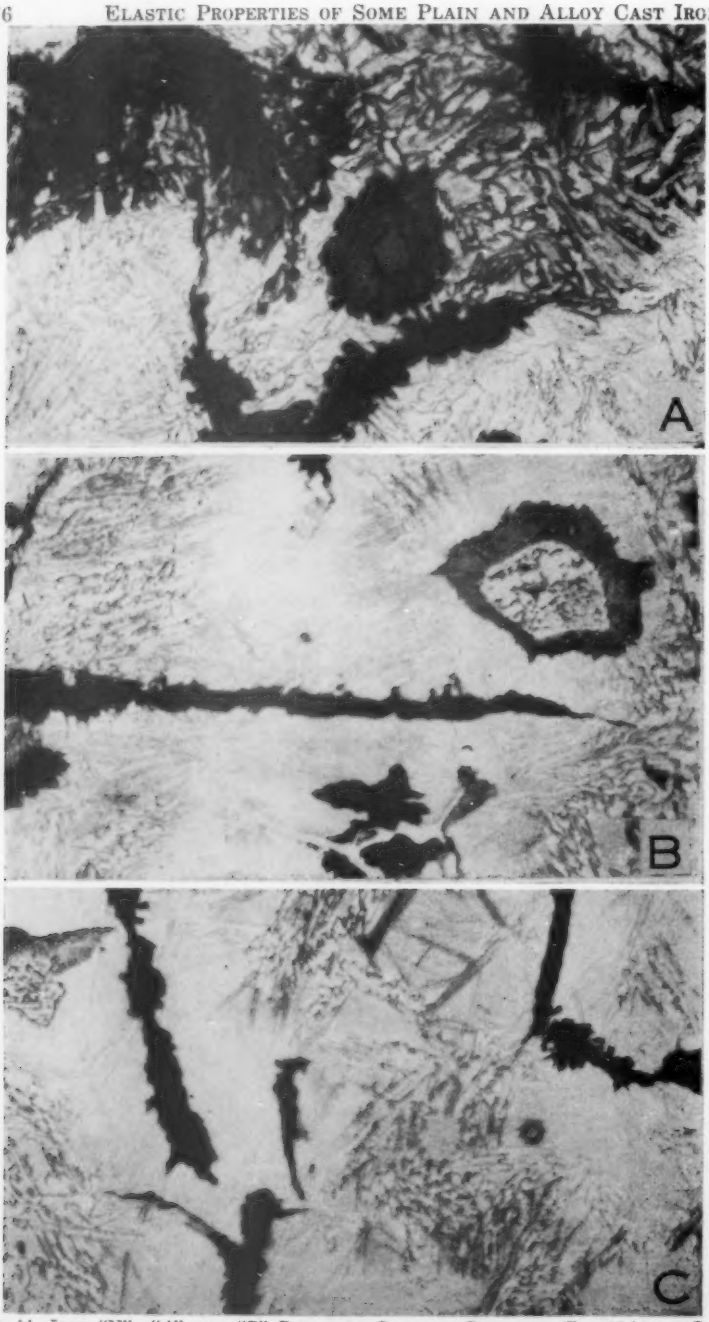

FIG. 14—IRON "N"—"*A*" AND "*B*" REPRESENT SPECIMEN SHOWN IN FIG. 13*A* AND *B*, *C* REPRESENTS SPECIMEN SHOWN IN FIG. 13*C* AND *D*. ETCHED. MAGNIFICATION x1500.

difference was observed in their structures (Figs. 13 and 14). Finer graphite globules and flakes are associated with a somewhat stronger bar (Fig. 13, C and D). It may also be observed that the higher Brinell number and relative modulus of elasticity were obtained with the bar possessing larger graphite nodules. Both specimens exhibited dendritic structures. The grayish-white areas (Fig. 13D), representing the midribs and branches of the dendrites, appear at higher magnification (Fig. 14C) as austenite at the initial stage of its transformation. A spot showing laminar graphite surrounding small crystals of manganese sulphide (Fig. 13D) is of interest.

53. A large portion of the free carbon of the lower strength transverse test bar (Fig. 13A and B, Fig. 14A and B) is present in the form of globules, consisting of aggregates of small graphite flakes. In the middle of some of these globules, the bluish-gray inclusions, presumably manganese sulphide, are plainly seen. A patch of eutectic-like graphite, resembling the Widmanstätten structure and associated with globular and coarse flaky graphite, is visible in Fig. 13B and Fig. 14A.

54. Other interesting structural features are the graphite eutectic situated within a graphite globule in Fig. 14B and the "fluffy" appearance of the edges of some graphite flakes shown in Figs. 13B and 14A. The secondary graphite, that is, hypereutectoid and eutectoid graphite, is generally deposited on existing graphite flakes in the form of a smooth band which is similarly oriented to the main body and is therefore difficult to show. Sometimes, however, the secondary graphite is deposited on the graphite lamellae in an irregular manner, so that the edges have a "fluffy" appearance[11, 12].

55. With regard to Widmanstätten structures, Morrogh[11] believes that the grain size of the original austenite does not determine whether the graphite will be deposited normally or in Widmanstätten form, and the conditions favorable for the development of the graphite Widmanstätten pattern are a controlled rate of cooling, neither extremely slow nor extremely fast, and a eutectic graphite structure consisting of a few very coarse flakes. The actual rate of cooling required to produce this structure must be very critical, as the graphite Widmanstätten pattern is seen in a fully developed form only very rarely.

56. The chemical analysis and Brinell hardness of two test bars represented in Fig. 15A, B, C and D are practically the same, but

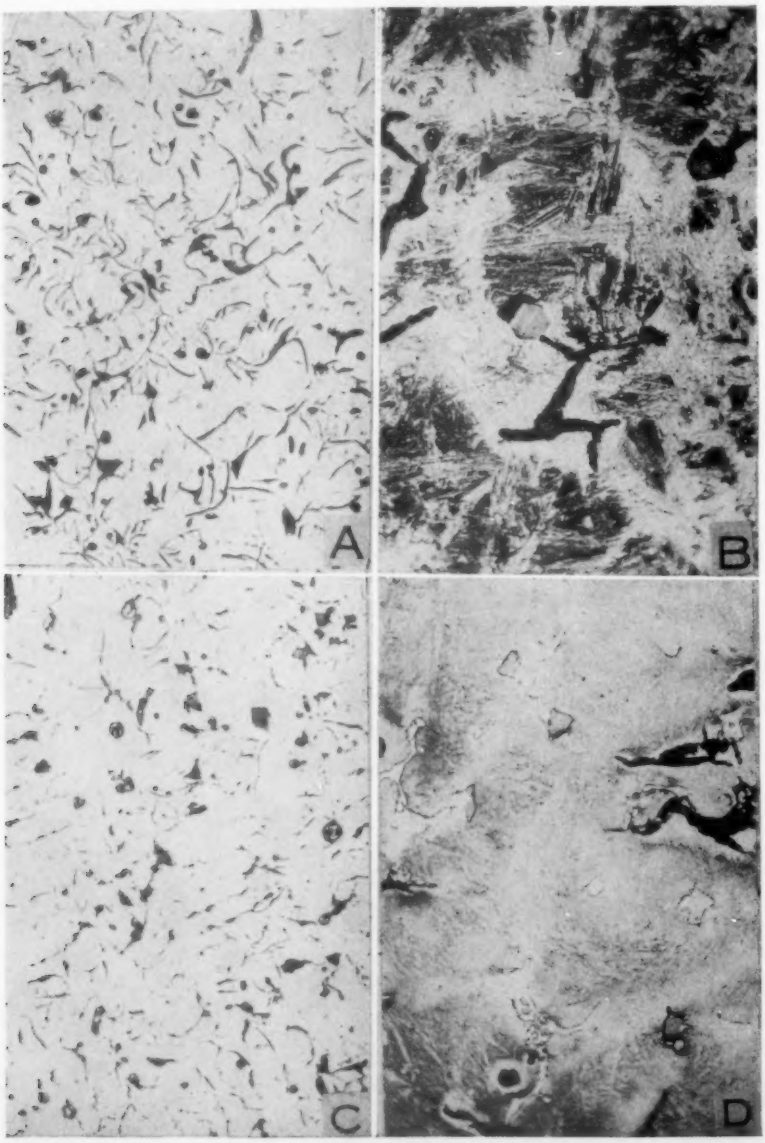

FIG. 15—IRON "N"—MAXIMUM TEMPERATURE, 1600°C. (2910°F.). POURING TEMPERATURE FOR "A" AND "B," 1450°C. (2640°F.); "C" AND "D," 1350°C. (2460°F.). MODULUS OF RUPTURE FOR "A" AND "B," 89,000 LB. PER SQ. IN.; FOR "C" AND "D," 112,100 LB. PER SQ. IN. $E_t = 17.3 \times 10^6$ LB. PER SQ. IN. FOR "A" AND "B" AND 18.7×10^6 LB. PER SQ. IN. FOR "C" AND "D." BRINELL HARDNESS NUMBER FOR "A," "B," "C" AND "D," 311. "A" AND "C," UNETCHED MAGNIFICATION, x100; "B" AND "D," ETCHED MAGNIFICATION, x500.

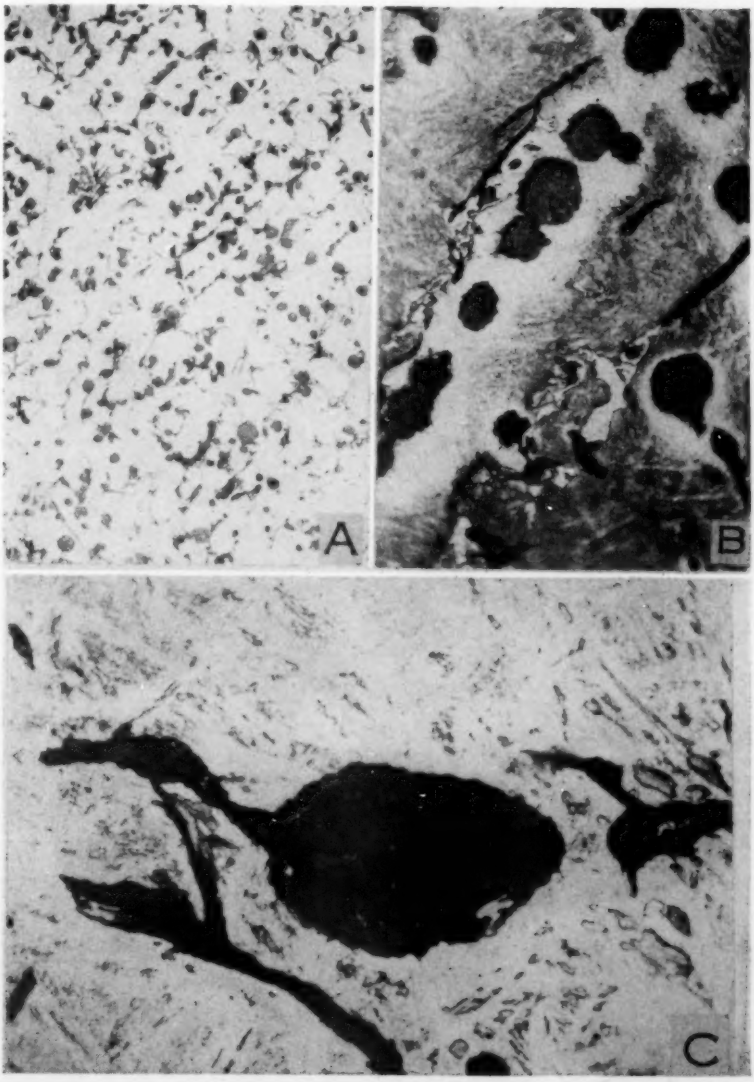

FIG. 16—IRON "N"—MAXIMUM TEMPERATURE, 1700°C. (3090°F.). POURING TEMPERATURE, 1350°C. (2460°F.). MODULUS OF RUPTURE, 104,000 LB. PER SQ. IN. $E_1 = 18.60 \times 10^6$ LB. PER SQ. IN. BRINELL HARDNESS NUMBER, 341. *A*—UNETCHED. *B* AND *C* ETCHED. MAGNIFICATION, *A*, x 100; *B*, x 500 AND *C*, x 1500.

their transverse strengths differ. The characteristic structural features of the higher strength bar (Fig. 15, C and D) are globular and flaky graphite, well developed dendritic pattern, free carbide and a fine acicular structure. The lower strength bar of the same heat (Fig. 15A and B) contained globular and whorl-like formations of graphite, coarse acicular structure and a small amount of fine pearlite. The dendritic pattern of this bar was less pronounced than that of the companion bar.

57. An interesting feature of the structure presented in Fig. 15B is the inclusion of a perfect hexagonal form with the light twinning-like band in the middle. It appears that this inclusion has been moved during solidification from its original seat and slightly rotated. It has the appearance of a cube resting on one of its edges. Somewhat similar inclusions but without the light band in the middle were shown by Allen[13] and Ellis[14]. Both of these authors described it as a manganese sulphide crystal. Ellis, however, remarks that manganese sulphide crystals may not be pure manganese sulphide, but rather mixtures of sulphides.

58. It is known that manganese sulphide inclusions possess a cubic crystal structure and appear in cast iron as dove-gray colored crystals of square, triangular, trapezoidal, etc. form. In steel, they are generally present as dove-gray colored globules. On the other hand, iron sulphide has a hexagonal crystal structure and is lighter[15] in color than manganese sulphide.

59. Whiteley[16] was able to show that, at temperatures above the solidus, the sulphide in steel consisted predomimantly of iron sulphide. The appearance of iron sulphide at these temperatures is due to the fact that the reaction $FeS + Mn \rightleftharpoons MnS + Fe$ will tend to proceed toward the left at higher temperatures. At very drastic quenching from the liquid state, this investigator was able to show that FeS was present in liquid steel containing 0.06 percent sulphur and 0.6 percent manganese. Iron sulphide may dissolve in the manganese sulphide.

60. Consideration of all of this evidence suggests that the inclusion shown in Fig. 15B is probably a mixture of manganese and iron sulphides and that the light band in the middle is the remnant of iron sulphide proper.

61. In the middle portion of the flake below the hexagonal inclusion just described (Fig. 15B), three dark lines crossing the flake at angles of about 60 degrees to its longitudinal axis may be

noticed. These lines resemble the needles described by Hanemann and Schrader[17] and also by Morrogh[11]. They have shown that secondary graphite sometimes forms small needle-like crystals of different orientation from the graphite flake. If the flake is in its dark position, then the needles appear bright, and if the flake is in its bright position the needles appear dark.

62. Figure 16 shows the structure of iron "N" heated to 1700°C. (3090°F.) and poured at 1350°C. (2460°F.). The modulus of elasticity and Brinell hardness of this bar are about the highest obtained in the present investigation. It seems that most of the free carbon is present here in the form of globules (Fig. 16A). A row of graphite globules is shown in Fig. 16B. They have a spongy-like appearance, some of them being associated with graphite flakes, as may be seen in Fig. 16C.

63. It appears as if they originated from the nucleus situated at the right end of the flake inside of the graphite nodule, but it is difficult to determine which of them, flake or globule, was formed first. If this globular graphite is of a temper-carbon nature, then the graphite flakes are eutectic graphite and the nodules are formed after solidification of the metal. Although the nodular formation of graphite is probably best developed in castings made from metal heated to 1700°C. (3090°F.), it cannot be stated that the high maximum heating temperature is responsible for such structure, because some nodular graphite was observed for the same iron "N" which had been heated only to 1400°C. (2550°F.) and poured at 1350°C. (2460°F.) (Fig. 13A and B). This structure is evidently characteristic for iron "N," and seems to be a contributing factor in obtaining the higher values of the relative modulus of elasticity and Brinell hardness.

64. The structure of the matrix of the specimen in Fig. 16B is acicular. The white area surrounding the graphite nodules, when resolved at higher magnification (x 1500), is shown in Fig. 16C. This structure resembles somewhat the micrographs presented by Davenport, Grange and Hafsten[18] showing the initial and second stages of transformation of coarse-grained austenite at 540°C. (1005°F.)

65. Microscopic examination indicates that a pearlitic matrix with the presence of some ferrite is responsible for the low strength of iron "L" as compared with irons "M" and "N." The relatively low strength and Brinell hardness of iron "M" as compared

with iron "N" may be caused by some pearlite in its structure. Acicular structure and fine graphite are associated with high strength in the irons examined. Iron "N" possessed large graphite globules and fine acicular matrix and had the highest Brinell number. In general, the globular formation of graphite seems to be a contributing factor in obtaining high values of relative modulus of elasticity and Brinell hardness.

66. It was found, when examining test bars of the same heat, that the bars possessing greater strength showed a pronounced dendritic pattern. Since it is commonly accepted that random distribution of graphite particles produces stronger cast iron than does dendritic structure, it may be inferred that the high strength bars showing dendritic patterns would possess still greater strength if their graphite particles were arranged at random.

SUMMARY

67. The results of this investigation may be summarized as follows:

1. The mechanical properties of three alloy irons ("L," a nickel-molybdenum iron; "M," a nickel-molybdenum-chromium, low-manganese, medium-silicon iron; and "N," a nickel-molybdenum-chromium, high-manganese and high-silicon iron) were determined by measurements under transverse loading.

2. The average transverse strength, ultimate total and elastic deflections, resilience and Brinell hardness of irons "M" and "N" were found to be superior to those of iron "L."

3. The maximum heating temperature showed no effect on the transverse strength of irons "L" and "M," but the moduli of rupture of iron "N" were somewhat higher for the maximum heating temperatures of 1600° and 1700°C. (2910° and 3090°F.) than for 1400° and 1500°C. (2550° and 2730°F.). The highest moduli of elasticity of all the bars tested were obtained with iron "N" at the heating temperature of 1700°C. (3090°F.), but in general no definite relation could be established between the relative moduli of elasticity and maximum heating temperature. The lower pouring temperatures, ranging from 100° to 150°C. (210° to 300°F.) above the liquidus, tended to increase the strength and relative modulus of elasticity of the irons examined. Neither maximum heating, nor pouring temperatures, exerted much influence on the

resilience values for irons "L" and "M," but a considerable improvement in these properties was observed for iron "N" when a lower pouring temperature was employed.

4. The elastic deflection curves of the alloy irons studied in this investigation were similar to those of the plain irons described in the previous paper, *i.e.*, they were straight lines in their lower portion, but beginning at a certain point (approximately 3/5 of the breaking load), they inclined toward the deflection axis.

5. Four relative moduli of elasticity were determined: E_1, calculated from the lower portion of the elastic deflection curve; $E_1(S)$, secant modulus corresponding to the load at which E_1 was calculated; E_2, ultimate modulus computed from the elastic deflection curve at the breaking point; and $E_2(S)$, ultimate secant modulus at the breaking load. The values of these moduli decreased in the following order: E_1, E_2, $E_1(S)$ and $E_2(S)$. There was a rather small difference between E_1, E_2 and $E_1(S)$ values, but $E_2(S)$ was considerably lower.

6. The ratios of the average ultimate plastic resilience W_4 (the area below the load-plastic-deflection curve between the origin and the ordinate drawn to the plastic-deflection curve at the point of rupture) and ultimate total resilience W_1 (area below the load-total-deflection curve and between the origin and the ordinate drawn to the total deflection curve at the point of rupture) were considerably higher for irons "M" and "N" than for iron "L."

7. There is a definite trend for the ratios $E_1(S)/E_2(S)$ and $E_2/E_2(S)$ to increase with an increase of ratio W_1/W_2, where W_1 is the ultimate total resilience and W_2 the ultimate triangular resilience, represented by a triangular area below a straight line drawn from the origin to the point of rupture on the load-total-deflection curve.

8. Comparison of alloy irons "L," "M," and "N" with plain irons "A," "B," and "C," previously investigated, indicates that:

(*a*) Iron "A," showing higher strength, elasticity and resilience values than companion plain irons, possesses strength and resilience equivalent to those of a nickel-molybdenum iron.

(*b*) The relative moduli of elasticity of iron "A" heated

to the maximum temperature of 1700°C. (3090°F.) are higher than those of alloy irons.

(*c*) The beneficial effect of the maximum heating temperature on the moduli of rupture and elasticity was more pronounced for the plain irons than for alloy irons. The effect of pouring temperature for both plain and alloy irons, was about the same, *i.e.*, these properties showed a tendency to increase with a decrease in pouring temperature.

(*d*) The plastic to total resilience ratios of plain iron "B" (a medium cylinder iron) are higher than those of alloy irons.

(*e*) If the proportion of plastic deflection to the total deflection at fracture is accepted as an index of plasticity of cast iron, an alloy iron "L" may be considered as being the most rigid and plain iron "B" the least rigid.

9. The structure of iron "L" consists of flaky graphite and pearlite. The matrix of irons "M" and "N" appears to be made up of the transition product of austenite, an "acicular" structure.

10. The graphite of iron "N" shows a tendency to form globules. This was particularly pronounced in the specimen of this iron when heated to the maximum temperature of 1700° C. (3090°F.) and poured at 1350°C. (2460°F.). It is probable that the nodular graphite structure is a contributing factor in obtaining the higher values of the relative modulus of elasticity and Brinell hardness. Some unusual structures of iron "N" were observed and a tentative explanation was offered for the following: a patch of an eutectic-like graphite resembling the Widmanstätten pattern; the fluffy appearance of the edges of some graphite flakes; an inclusion, presumably manganese sulphide, of a perfect hexagonal form with the light twinning-like band in the middle; and the dark lines observed on a graphite flake and crossing it at about a 60° angle.

ACKNOWLEDGMENT

68. Grateful acknowledgment is made to L. D. Jones and Houston Babb for assistance in this investigation.

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DISCUSSION

Presiding: A. E. SCHUH, U. S. Pipe & Foundry Co., Burlington, N. J.

F. G. SEFING[1]: The data presented on elastic properties are very interesting, first of all because they are a little disturbing to me. If someone had asked me what the elastic properties would be of an iron that had been heated to 3000°F. as compared to one heated to 2750°F., I would have suggested that the modulus of elasticity would have dropped in the case of the metal poured at the higher temperature. The reason for saying that would be that the iron heated to 2750°F. is stronger than the one heated to 3000°F. and generally irons with higher strengths show higher moduli of elasticity.

I would like to point out a few things that do not seem exactly clear to me. In Figs. 11, 12 and 13, it is shown that the higher melting temperatures have a profound influence on throwing the fine graphite, as well as in a sort of dendritic pattern. Flinn and Reese*, in a paper presented before A.F.A., and Crosby, Timmons and Herzig**, show results indicating that when a normal graphite pattern is compared with the dendritic graphite pattern, there is a marked increase in strength with the normal graphite pattern. There is no doubt that heating to higher temperatures throws the dendritic graphite, but what disturbs me is that there should be any indication of higher strength with the dendritic pattern. It would be interesting if the data might be continued to include structures that are wholly normal graphite. That is to say, those irons that are melted at the higher temperatures should be inoculated with any of the common inoculants to throw the normal graphite pattern and then a comparison made between the elastic properties of irons melted at low and high temperatures. It seems to me

1 International Nickel Co., New York, N. Y.

* Flinn, R. A., and Reese, D. J., *"The Development and Control of Engineering Gray Cast Irons,"* TRANSACTIONS, American Foundrymen's Association, vol. 49, pp. 559-607 (1941).

** Timmons, G. A., Crosby, V. A., and Herzig, A. J., *"Produces High Strength Iron,"* THE FOUNDRY, December, 1938 and January, 1939, pp. 28-30, 75, 76, and 30, 31, 86, 88, respectively.

that distinctions should be made between irons with different graphite forms. In so many cases, we find the dendritic pattern with its fine graphite. There are so many undesirable things about the fine dendritic graphite pattern from a wear viewpoint and a low tensile strength viewpoint that we can hardly afford in practice to jeopardize the iron by permitting it to go into service with a dendritic structure.

Another thing which interested me was that the paper indicates that low pouring temperatures are throwing higher tensile strengths than the higher pouring temperature. One of the earlier papers that showed optimum pouring temperatures in the neighborhood of 2700°F., was by DiGuilio and White*, with lower pouring temperatures causing a marked reduction in the strength. In practice, I have found that it is definitely true in a wide variety of cast irons, that as the temperature of pouring drops below 2600°F., the mechanical properties fall off rapidly. I would like to see these two apparently controversial points brought together.

Another point which interests me academically is conclusion No. 9, where reference is made to the acicular structure as being called "acicular pearlite" or "acicular ferrite." Evidence has been shown that these needles, or the acicular structure, are definitely ferrite. In my own investigations, I have substantiated this contention from several viewpoints.

MEMBER: With regard to the point Mr. Sefing brought up, I rather think you will find that the modulus of elasticity would be a function of the total graphite. Provided it is not a material like malleable iron, it would be much nearer a function of the total graphite than of distribution. It would be more a function of the distribution of size and shape than it would be of the amount. I know it is possible to get a very good curve in plotting, total carbon and silicon plus 3.10 per cent silicon, say, against the modulus of elasticity, but if that is plotted against strength, it does not produce very good correlation.

The same is true with phosphorus. Apparently, it does not affect the action of the carbon plus 3.10 per cent silicon on stiffness, but it affects the strength to a considerable extent.

I am not at all surprised to find that nothing done to the iron that did not change the amount of graphite formed would affect the modulus of elasticity, for anything done to improve the distribution of it would help the strength.

MR. SEFING: By way of offering some evidence substantiating the contention that graphite size and shape affect the elastic modulus, I had occasion about a year ago to produce a particular composition iron in very small piston rings which were to have the highest possible elastic modulus. This was achieved by producing the castings almost white and malleableizing or annealing which threw out much of the combined carbon in nodule form. The modulus went right up, compared with the same composition cast gray to about the same hardness.

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* DiGuilio, A., and White, A. E., *"Factors Affecting the Structure and Properties of Gray Cast Iron,"* TRANSACTIONS, American Foundrymen's Association, vol. 43, pp. 531-572 (1935).

MEMBER: Regarding the effect of pouring temperature on strength, etc., in general, it is found that as long as the mold is completely filled with liquid metal, the pouring temperature does not affect the strength until the metal is poured so hot it results in a hot mold effect. If it is lacking in soundness because of a little low pouring temperature, the strength is improved by increasing the pouring temperature. If the mold is not quite dry, for instance, it is possible to get very good results by pouring hot enough to dry the mold and still have the metal liquid after the commotion is all over.

C. H. JUNGE[2]: We find, in malleable iron, the total carbon present is the determining factor in the modulus of elasticity. If there is a very great number of fine temper carbon nodules, about the same results are obtained as with much coarser nodules. So the total carbon apparently is the determining factor and not the particular size distribution of the carbon.

J. S. VANICK[3]: Following up this elasticity discussion, it seems to me we are getting into a point that this paper attempts to clear up in combining the elastic and the plastic deformation. Quite a bit of emphasis is put on plastic deformation in paragraph 39 as a factor in avoiding cracked castings for instance. I am wondering whether this discussion stops within the true elastic range or whether it is taking in the entire plastic plus elastic range.

MEMBER: No matter how it is measured, the lower the modulus, the greater the plastic deflection. If we take any one of the authors' modulus of elasticity measurements, or if we take the simple beam formula, at the ultimate we find a very good correlation between the plastic deformation and that modulus. It would be awfully hard to unscramble them, and I would say they invariably go along together.

MR. VANICK: It seems as though the authors are making a distinction between the percentage of plastic to the total deformation when they pour these six different types of irons. Irons A and C seem to stick in their class; they seem to show the same percentage of plastic to the total deformation. They demonstrate this matter of always expecting the same modulus for a fixed total carbon content. However, alloys might bring in conditions that alter that relationship. For example, the alloy irons with progressively lower total carbon contents show an increasing plastic (and total) deflection accompanied by an increasing modulus.

MEMBER: There are 25 different irons, including one with 2 per cent phosphorus which is off the curve, and the martensitic nickel iron is decidedly off the curve. When there is a totally different matrix, like the high phosphorus or the martensitic irons, I believe you depart from that rule. But as long as fairly normal compositions are used, the two go along and function with each other.

CHAIRMAN SCHUH: The fact that our commentators seem to be more or less lost in this, I think, points out the desirability of studying this Bureau of Standards paper very carefully. One thing we can all be as-

[2] National Malleable & Steel Castings Co., Cleveland, O.
[3] International Nickel Co., New York, N. Y.

sured of is that the work reported was carried out as precisely and faithfully as present-day science in cast iron permits, so I do think we ought to give the paper considerably more attention and submit written comments.

MESSRS. SAEGER and KRYNITSKY (*authors' closure*): The authors wish to thank those who, by their discussion not only made a valuable contribution, but also emphasized the importance of the problem investigated.

Mr. F. G. Sefing questioned that there should be any indication of higher strength with dendritic pattern. This statement is in accord with the authors' opinion as stated in paragraph 66. The authors believe that the high strength bars showing dendritic patterns would possess still greater strength if the graphite particles were arranged at random.

In reference to Mr. Sefing's argument relative to the correlation between low pouring temperatures and high tensile strength the authors wish to refrain from theoretical speculation, but do reiterate that the data obtained from their transverse strength tests led them to conclude that lower pouring temperatures, ranging from 100° to 150°F. above the liquidus, tended to increase the transverse strength and relative modulus of elasticity of the irons examined. This tendency was more pronounced in plain irons than alloy irons.

It was interesting to learn that acicular structure of molybdenum irons is considered to be ferrite rather than pearlite. The authors agree that total carbon content is an important factor in the modulus of elasticity. Likewise the size, shape, and distribution of graphite particles also play a significant role. For example, globular formation of graphite seems to be a contributing factor in obtaining higher values of relative moduli of elasticity and Brinell hardness. It was gratifying to find this point also substantiated by Mr. Sefing.

Some Causes of Gas Unsoundness and How to Eliminate Them

By H. L. Smith*, Pittsburgh, Pa.

Abstract

This paper was prepared as a contribution toward the science and art of brass and bronze founding to help increase production. The author points out melting practice as one of the important factors which causes considerable trouble in the foundry and states that it is generally overlooked, or unknown, when trying to locate causes of excessive loss due to porosity or other casting defects. He states that in the melting of copper-base alloys, the reactions and inter-reactions between hydrogen, oxygen, carbon and sulphur are of fundamental importance, resulting in gas unsoundness during solidification of the alloys, and advocates proper control of furnace atmosphere. He describes in detail the effect of oxygen and hydrogen, carbon monoxide, charcoal, etc. and explains how the reactions take place in open-flame, crucible and electric furnaces. The paper is of value to the furnace operator because the technical data given is translated into everyday, practical language.

1. In these strenuous times when the conservation of strategic materials is one of the most important problems facing all of us, it is extremely important that we look again into those things which will help to reduce the number of lost castings. In this paper, the author hopes that he may contribute something toward the science and art of brass and bronze founding and thus help to increase production.

2. All foundrymen know that the molding practices, gating, cores, sand, pouring technique, etc., are always important factors to be reckoned with in the production of sound castings. For the purpose of this paper, it is assumed that the general foundry practice is quite satisfactory in this regard in the majority of foundries.

3. There are other important factors beside these, however, which cause considerable trouble in the foundry that are over-

* Federated Metals Division, American Smelting & Refining Co.

Note: This paper was presented at a session on Non-Ferrous Founding at the 46th Annual A.F.A. Convention, Cleveland, Ohio, April 20, 1942.

looked, or sometimes unknown, when the foundryman is trying to locate the cause of excessive losses due to porosity or other casting defects.

4. The author does not believe that the average melter realizes that, by abandoning the old coke-fired pit-furnace for oil or gas-fired furnaces, or even for the electric furnace, he has complicated his melting problem to a considerable degree. It is probably also true that he does not realize the importance of the melting conditions, and how they influence the soundness of the casting, and the properties of the alloy being melted.

5. In the melting and pouring of copper-base alloys, and particularly the tin and silicon bronzes, the reactions and inter-reactions between hydrogen, oxygen, carbon and sulphur are of fundamental importance. These reactions are understood readily by the technical worker, but the author wonders whether they really are understood by the man that actually does the melting. It is with this thought in mind that the author brings to attention the good work of some recent investigators, and will discuss the same in the light of experience and then try to translate the technical data into everyday, practical language.

GASES IN BRONZE

6. The reactions just mentioned have been studied by a number of experimenters. For example, Pearson and Baker[1] show that gas unsoundness in cast bronze may result from the evolution of hydrogen, water vapor, carbon monoxide, or sulphur dioxide during solidification of the alloys. Also that hydrogen and oxygen co-exist in molten bronze and recombine during solidification with a resultant evolution of steam.

Oxygen and Hydrogen

7. These authors show by experiment that, if the unsoundness were due only to the solution, and subsequent liberation of hydrogen formed by dissociation of the moisture, the extent of unsoundness would have steadily increased with increased moisture concentration. The maxima and minima in the unsoundness curves actually found, clearly indicate that another factor operates, and in fact, the curves can be explained only by assuming that both oxygen and hydrogen are dissolved by the melt and that an equilibrium exists between the concentration in the melt.

[1] Journal, British Institute of Metals, August 1941.

8. To confirm this conclusion, they show the effects of oxidation, and deoxidation on melts previously exposed to moist nitrogen for 45 min., and state that additions of phosphorus or aluminum, just before pouring, eliminated the greater part of the unsoundness, and that aluminum, which has a greater affinity for oxygen than phosphorus, was the more effective in this respect. Thus, it appears that removal of the bulk of oxygen present, or its conversion to an inert oxide, reduces the quantity of steam formed during solidification and reduces the extent of gas porosity; also, that the concentration of hydrogen in the melt is unlikely to be affected by such additions. The fact that this hydrogen did not give rise to such severe unsoundness as it would have done in the presence of oxygen, indicates that steam evolved during solidification is more likely to be trapped in the casting than is hydrogen, or the solid solubility of hydrogen is increased by removal of oxygen from the melt.

Carbon Monoxide

9. Bolton, in discussing Pearson and Baker's paper, brings out the dangers of an atmosphere rich in carbon monoxide, and states that, when melting in an indirect-arc furnace, very high porosity, causing 5 per cent or more leakers, has been noted. He also states that investigations show that under certain operating conditions, a very high concentration of carbon monoxide is possible, and that many gas analyses have shown up to 60 per cent carbon monoxide in the melting atmosphere. Not one, but many heats made under these conditions, were studied, and not only was the percentage of leakers on hydraulic tests high, but test bars were relatively low in strength.

10. Bolton further states that, in this particular case, the introduction of measured volumes of air into the furnace was studied, and the flow adjusted to give an actual analysis of CO_2, no CO, and at times a slight excess of oxygen. The results of the changed practice were highly satisfactory, resulting in (1) rapid drop in porosity, (2) rapid increase in test-bar strength, (3) about a 20 per cent increase in electrode consumption and (4) to their considerable surprise, current consumption decreased somewhat, which more than offset the increased electrode expense.

Effect of Charcoal

11. In addition, Bolton noted that pouring this alloy "and also

the alloy containing copper 88, tin 10, and zinc 2 per cent, on to either charcoal or coke results in marked porosity," and states that if charcoal or coke is placed on top of the metal no discernible trouble results. However, if the charcoal or coke (after being on hot metal) is not removed from the hot pot, and fresh metal poured thereon, porosity is quite likely. This has been observed repeatedly. Also, pots with coke or charcoal in them have been heated under burners. Presumably these treatments (holding on hot metal, and heating to redness in a pot) would drive off all moisture. If the moisture was driven off (and pieces removed indicated it was) what, asks Bolton, apart from the carbon (and products of its interaction with the metal, presumably largely carbon monoxide), is responsible for these phenomena?

Effect of Crucible

12. Bolton made a similar observation in his research laboratory during the melting of these bronzes in a high-frequency induction furnace. When using a plumbago crucible, regardless of how well burned out, he found that it was not possible to attain physical values on sand-cast test-bars comparable with those attained in the foundry, ductility in particular being very low. The atmosphere in such melting was air plus the combustion products from the crucible. By the use of a silica crucible consistently high values were attained. Such results were obtained without regard for the covering of the molten metal, provided that no carbonaceous matter was present. The results obtained with a carbonaceous covering were very poor indeed.

Cumulative Effect of CO

13. Of particular interest is Bolton's closing comment about carbon monoxide that the effects of this gas are definitely cumulative. He has shown by experiment that (especially with an all-virgin-metal charge, the copper containing some oxide) the first heat may show little effect. When returns in cycle are put over and over through the same carbon-monoxide-rich atmosphere, the porosity becomes evident and soon very bad indeed.

14. Further in this connection, Drs. Floe and Chipman, in their paper on the effect of impurities on the solubility of sulphur dioxide (SO_2) in molten copper, state that any carbon in the copper will react with SO_2 to form CO, and CO_2 (carbon monoxide and carbon-dioxide).

15. Up to this point, reference has been made to the work of several investigators and the results of their tests have been quoted freely. Since extensive tests have been made by these and other investigators, and more recently by H. B. Gardner, research associate, Non-Ferrous Ingot Metal Institute, Bureau of Standards, the author will not add more technical data from his own tests, except to say that all of the brass and bronze alloys in the plants of the company with which he is affiliated, are melted in open-flame, reverberatory or U.S. furnaces and crucible fired with either oil or gas. From observations made over the past 20 years, both in the research laboratory and in the plant, he has found that the presence of hydrogen, as well as carbon and sulphur, are sources of trouble when gassed metal is encountered.

16. To correct the trouble, flame adjustment to get maximum CO_2 content with a slight excess of O_2 and no CO in the products of combustion is particularly important. To maintain these conditions, it is desirable to have what the average melter calls a slight vacuum in the furnace. The term "slight vacuum" really means that a very small excess of air is sweeping through the furnace.

THEORY TRANSLATED TO PRACTICE

17. The author now will translate some of his own observations, which agree precisely with the work of Pearson and Baker, Bolton, Floe and Chipman, into everyday foundry control and discuss how these reactions take place; first, in open flame furnaces; second, in crucible furnaces, and third, in the electric furnace.

Water Formed in Gas-fired Furnaces

18. Many melters ask how water can possibly get into molten metal when water boils at 212°F. and the metal is around 2000°F. The explanation for this is quite simple, once the reaction is understood. But even then, few melters realize how much water really is formed during the melting of a heat of brass.

19. To give some idea, there are 11 gallons of water formed for every 1,000 cu. ft. of natural gas burned. Knowing this, one can easily compute the amount of water formed during the melting of any particular quantity of metal. As an example, to melt 1,000 lb. of 85-5-5-5 and bring it up to a temperature of around 2075°F., will take approximately 2,000 cu. ft. of gas. Since 1,000 cu. ft. of gas contains 11 gallons of water, and we consume 2,000 cu. ft. of

gas to melt the brass, there is formed 2x11 gallons, or 22 gallons of water for every 1,000 lb. of brass melted.

Open-flame Furnaces

20. Now, as has been explained by the water vapor dissociation reaction, the one thing that will dissociate water when it is formed in an open-flame furnace at high temperature, is carbon, and naturally there is plenty of that in the fuel being burned. The carbon (c) takes the oxygen (O_2) from the water (H_2O) forming carbon monoxide (CO) thus releasing the hydrogen (H). This reaction is written chemically as follows:

$$H_2O + C = CO + H_2$$

21. The hydrogen liberated from this reaction then dissolves in the melt but the melter cannot see this reaction take place and thus goes on with the melting procedure, bringing the furnace up to temperature in the usual way until he is ready to tap.

Effect of Pouring

22. Now the reaction reverses. When the metal is poured through the air, the surfaces that are exposed oxidize. Then the hydrogen dissolved in the metal, immediately reduces the freshly-formed oxide back to metal and forms water again, according to the reaction $CuO + H_2 = Cu + H_2O$. This water is then trapped in the metal as it cools and, therefore, causes the little shiny holes you have seen many times and probably called them "gas holes."

Crucible Furnaces

23. In regard to crucible furnaces, many foundrymen feel that what has been said may be true with open-flame furnaces; but with crucible furnaces, the flame never comes into contact with the metal and, therefore, the metal cannot become gassed because of improper combustion. Nevertheless, in many cases, gassed castings coming from metal that has been melted in a crucible furnace are found the same as with metal which has been melted in an open flame furnace. With the idea in the melter's mind that he cannot gas metal in a crucible because the crucible protects it from objectionable furnace gases, he feels that he has trouble with gassed metal, and usually blames the metal. When a thorough investigation is made, however, it usually is found that something else happens of which many melters are unaware, and that is that the

crucible is nothing but a porous membrane or sponge, so to speak. Therefore, hydrogen and other objectionable furnace gases can penetrate the crucible and into the metal, the same as if the metal has been melted in an open-flame furnace under reducing conditions.

24. Another factor that must be reckoned with in crucible melting is that copper and copper-base alloys absorb carbon from the crucible itself, which, as stated before, reacts with oxygen during the pouring process to form CO and CO_2, the same as hydrogen combines with oxygen to form water vapor.

Electric Furnaces

25. In regard to melting in the electric furnace, the author would like to offer the suggestion that carbon solubility in the alloy might explain the findings of Bolton. The carbon, formed through the reduction of CO by the metal and small amounts of CO_2 in the furnace atmosphere, get up into the furnace arc and there are reduced to CO according to the reactions:

$$2Cu + CO = Cu_2O + C$$
$$Cu_2O + CO = CO_2 + Cu$$
$$CO_2 + C = 2\,CO$$

26. Thus, the generally accepted practice of melting in a slightly oxidizing atmosphere is justified, except to mention that elements having a high affinity for oxygen, such as phosphorus, if present, will hinder the expulsion of reducing gas by oxidation.

POROSITY UNDER OXIDIZING ATMOSPHERES

27. From the foregoing, it might appear that, by melting in a slightly oxidizing atmosphere, all foundry troubles should be eliminated. This is not always true because in some cases porosity also is encountered with metal melted under oxidizing conditions. In this case, the reaction of carbon (C) and oxygen (O) may again be the source of trouble. It is quite possible that, if metal containing a slight amount of oxygen is poured into a mold that has been faced with some carbonaceous material, the carbon in the mold facing or in the core compounds, may combine with the oxygen in the metal to form CO and CO_2, thereby causing porosity. With carbon in the metal the carbon also can react with the moisture in the sand to form carbon monoxide and hydrogen and thus again cause porosity.

CONCLUSION

28. In conclusion, the discussion shows

(1) That with water formed as a product of combustion, if free carbon is present, the carbon will react with the water vapor to form carbon monoxide releasing the hydrogen which goes into solution in the metal during the melting process;

(2) When the molten metal is subsequently poured, some of it oxidizes, at which time the contained hydrogen recombines with the oxygen to form metal and water vapor again;

(3) This reaction takes place quickly, not in minutes or hours, but in a matter of seconds;

(4) That carbon is soluble in small amounts in molten copper and copper-base alloys which react with oxygen to form CO and CO_2. This reaction proceeds the same as the hydrogen-oxygen reaction and both can take place simultaneously;

(5) That molten metal can absorb sufficient carbon from the crucible, if melted in graphite, or from charcoal, if poured over it, to cause gas porosity;

(6) That the probable answer to the accumulative effect of carbon gas porosity in the electric-arc furnace is due (a) to the reaction of carbon monoxide with the metal to form carbon and metallic oxide, (b) to the reaction of the metallic oxide with more carbon monoxide to form minute amounts of carbon dioxide, and (c) to the reduction of these minute amounts of carbon dioxide in the arc permitting the reaction to proceed from the start.

DISCUSSION

Presiding: M. V. HEALEY, General Electric Co., Schenectady, N. Y.

Co-Chairman: D. FRANK O'CONNOR, Watts Regulator Co., Lawrence, Mass.

J. W. BOLTON[1]: This paper is of extreme interest to us because, prior to its publication, there were but one or two investigators who dared say that carbon in itself would, due to the reaction with oxygen and water

[1] Lunkenheimer Co., Cincinnati, Ohio.

vapor, have much to do with porosity of bronze. Last year an extensive research paper dealing with questions of porosity was published and did away with the possibilities of carbon reaction and the formation of carbon monoxide completely, saying such a thing was not possible.

Our company has been working with this problem for many years, and we are glad to confirm everything the speaker says relative to what takes place and the reactions, including those of the mold, of carbonaceous material within the mold, of carbon in crucible and in induction melting, of carbon in electric arc furnace melting, of methane and hydrogen and an excess of carbon monoxide in reducing flame in gas furnace melting.

MEMBER: I agree with the author and with Mr. Bolton that these so-called gas conditions accumulate in the furnaces. We found porosity in castings and by careful melting conditions and using a slightly oxidizing condition, we are able to eliminate almost 90 per cent of it. That does not mean the gas holes are entirely eliminated or that the gas after melting comes from the furnaces. There are other points to be considered, one of the most important of which is the method of pouring.

MR. SMITH: You are absolutely correct that there will still be a little porosity. However, the causes of this small amount of porosity must be studied scientifically because the material in the paper has been given in quite an elementary way.

I have not dealt at all with any of the partial pressures or the equilibriums involved. However, when considering carbon and its effect on gas, quantities in the neighborhood of 0.0004 per cent are being considered. Some authors have suggested that 0.003 per cent carbon is soluble but, from our work, we have found that is quite high.

Casting Cleaning in a Gray Iron Foundry

By Howard B. Nye*, Watertown, N. Y.

Abstract

Super-clean castings are easier and cheaper to machine, have greater eye appeal, and in many industries are absolutely essential to a first quality final product. Castings may leave the foundry cleaned and finished just enough to pass minimum inspection requirements, or they may be delivered cleaned in such a way that they are a credit to the foundry which produces them, since they reflect the quality workmanship which must go into the making of any good casting. It is the purpose of this paper to illustrate that by the application of modern methods to this often neglected phase of foundry operations, it is possible not only to produce super-clean castings, but also to effect a substantial lowering of cleaning costs as well. The first section of the paper consists of a brief chronological coverage of the most commonly used cleaning equipment, while the latter part of the paper discusses, with the aid of actual cost figures, the practical application of improved casting cleaning methods.

Part I—Cleaning Equipment

Shake-Out: The First Cleaning Operation

1. In a production foundry, the cleaning process begins at the shake-out. Whenever possible, it is desirable to place the castings on a vibrating grate to remove excess molding and core sand before the casting is transported to the hot storage area. Some castings are not, however, well adapted to such handling, since they are too fragile, have arbors which are easily broken, or have been made with chills which are so small that they go through the grate, and burn the conveyer belt. When shaking-out heavily cored castings,

* Foundry Engineer, New York Air Brake Company.

Note: This paper was presented at a Plant and Plant Equipment Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 23, 1942.

the large amount of unbonded material which is introduced into the sand system causes some difficulty, since it must be rapidly built up and conditioned so that it may be used as a molding sand. The use of present day bonding agents and conditioning equipment tends, however, to nullify this objection. It is a mistake to expect too much cleaning action from the initial shake-out, since sand does not peel well from hot castings. For this reason, many foundries store or convey the castings after they leave the mold until they are cool, when they again place them on a shake-out grate or subject them to preliminary tumbling to remove excess sand. Which one, if either, of these methods is used depends much upon local shop conditions. In any event, preliminary cleaning is usually desirable and economical.

TUMBLING BARRELS

2. If the castings are of such design that they will stand rough handling, tumbling, which is one of the oldest methods of casting cleaning, should be considered. Tumbling offers the following:

Advantages:

(1) The direct labor cost is low.

(2) The initial cost of the equipment is nominal.

(3) The smoothly peened finish of tumbled castings is sometimes highly desirable.

Disadvantages:

(1) Breakage is often costly.

(2) Castings are not truly cleaned, since, as well as not always removing all of the surface sand, tumbling pounds some of it into the surface of the metal, thus decreasing tool life when the casting is machined.

(3) The cost of the power necessary to operate tumbling mills is disproportionately high compared to other methods of cleaning.

(4) Mill wear is sometimes objectionable from an appearance standpoint.

(5) Tumbling is a hazardous operation and results in many serious injuries which are not only regrettable but uneconomical.

When all of the operating figures are carefully compiled, the cost per ton of tumbling castings is a great deal higher than the direct labor cost, often used as a comparative figure, would indicate.

3. There have been developed several special types of tumbling equipment, such as, for instance, the continuous shot return barrel, and a type of barrel which uses water as well as shot as a tumbling medium. Whether or not such equipment offers any great advantage over conventional tumbling, depends much upon the conditions of the individual case.

AIR BLAST BARRELS

4. Air blast barrels, of which there are many types, have been widely used in the past for casting cleaning. They offer the following:

Advantages:

(1) Compared to tumbling, breakage loss is low.

(2) Casting finish is unusually good.

(3) If operated in groups, the direct labor cost is low.

Disadvantages:

(1) They use large amounts of costly compressed air.

(2) They are slow compared with other more modern methods.

(3) In proportion to the comparative tonnage that they will produce, the initial cost is high.

Except in special instances, this type of equipment is being displaced by faster cleaning, more efficient units.

AIRLESS BLAST BARRELS

5. About ten years ago there was marketed a type of airless blast equipment, which, through development, has become one of the fastest and most efficient methods of cleaning. As most foundrymen perhaps already know, this airless equipment consists of a wheel which hurls the abrasive by centrifugal force, this producing a hard-hitting, thorough cleaning blast. These centrifugal blasting units, similar to the machine illustrated in Fig. 1, have been very successfully applied to barrels. They offer the following:

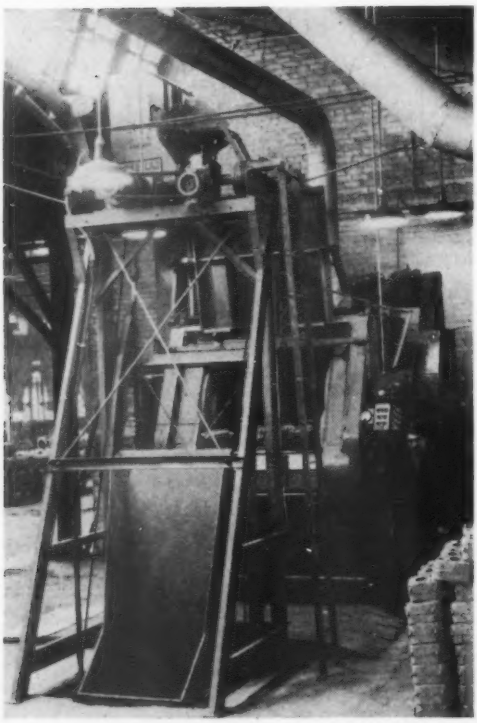

FIG. 1—CENTRIFUGAL BLASTING UNIT APPLIED TO ROTATING BARRELS.

Advantages:

(1) The cleaning process is very rapid.

(2) Breakage loss is low.

(3) The castings are super-clean.

(4) No costly compressed air is used.

(5) The loading and unloading facilities which are usually supplied with this type of equipment, make for increased operating efficiency compared to other barrel methods.

(6) The operation is fairly free from accident hazards.

Disadvantages:

(1) The first cost of the equipment is comparatively high.

(2) Heavily cored castings carry away considerable costly metal abrasive.

(3) Unless carefully managed, the maintenance of such a machine can be burdensome and expensive.

Any castings of such design and dimension that they can be run in a blast barrel can usually be cleaned better and cheaper in an airless mill, than by any other method.

AIR BLAST ROOMS

6. Sand, shot, and grit blast rooms are often used for cleaning a wide variety of castings. They are made in many forms varying all the way from a simple ventilated inclosure equipped with a blast tank, to large automatic abrasive return type rooms in which the castings are handled by means of cars or conveyers. They offer the following:

Advantages:

(1) They are very flexible in that it is possible to achieve a wide range of finishes and an almost infinite variety of work.

(2) Breakage losses are at a minimum.

(3) When it is necessary to "spot" blast production castings in localized areas, sand blast rooms are well suited to the job.

Disadvantages:

(1) They use large amounts of costly compressed air.

(2) The direct labor cost is high.

(3) Since this operation is hazardous, the operator must be provided burdensome safety equipment.

Most any foundry producing a wide variety of castings should have at least one blast room. However, except in special cases, it is seldom desirable to clean large volumes of production castings by this method.

TABLE BLASTS

7. Table blasts which are a production modification of blast rooms are available, equipped for either air or airless blasting. In most cases, the airless equipment which is usually the more costly of the two is by far the most efficient. They offer the following:

Advantages:

(1) The operator is able to work outside the blasting area.
(2) The operation is continuous, hence, high production is possible.
(3) Breakage loss is negligible.

Disadvantages:

(1) They are limited as to the size and type of casting which they can handle.
(2) The work usually has to make more than one pass through the blasting zone.
(3) The first cost is comparatively quite high.

SPECIAL AIRLESS BLAST CABINETS

8. During the past few years many special conveyer type cleaning machines, equipped with airless blasting units, have been installed in production foundries. The castings are suspended by means of work hooks on a chain conveyer which by successive moves indexes the castings into the blasting zones where they are rotated until cleaned. The conveyer continues to index automatically, thus making the process continuous. Any foundry having a cleaning problem involving production castings, which are too large for standard airless barrels, can usually solve the problem by adapting this type of equipment. If such a modernization program is carried out, it is, as a rule, one of the most profitable of foundry equipment investments.

SNAGGING

9. After the sand has been removed from castings, they are usually chipped, ground, or, in some other way, smoothed up. In general, any casting small enough to be handled conveniently by the operator can be snagged better and cheaper on a fairly large floor stand grinder than by any other method. Castings which have only flat faces to be ground can be very economically finished on a disc grinder of suitable design and dimension. Castings which are too large to be picked up by the workman are usually ground with a swing frame grinder, or chipped and ground with portable tools.

Snagging Equipment

10. There are several considerations in connection with grind-

ing equipment which are very important. Great care should be taken to see that any new grinding unit has the right spindle speed for most efficient wheel performance. Floor stand and swing frame grinders are available with multi-speed drive equipment. This is a very desirable and economical feature which should be used wherever possible. If large numbers of portable tools are necessary to handle a given production, high cycle electric tools are the most economical to use.

11. Where the production is not large enough to warrant the investment in the motor generator set necessary for high cycle operations, pneumatic tools are available in a wide range of types and sizes. Vertical spindle pneumatic grinders which may be equipped for either sanding or grinding are very powerful and do excellent work at a rapid rate. Where it is not convenient to use the larger vertical spindle type of grinder, tools which mount small high speed cone or cylinder wheels are used with good results.

Grinding Wheels

12. Grinding wheels are available in two general classifications; vitrified bonded wheels which operate most efficiently at about 6000 surface ft. per min., and resinoid or rubber bonded wheels which operate best at about 9500 surface ft. per min. The high speed type of wheel cuts somewhat faster than the medium speed type. However, most gray iron foundries find it uneconomical to make any major changes in their equipment to take advantage of this faster cutting quality.

13. In selecting a grinding wheel it is a good plan to make cutting quality which has a direct bearing on the production efficiency a major consideration. After the desired production has been obtained, the grading may be worked back until a satisfactory balance between cutting quality and wheel life is achieved.

14. Grinding wheels can be one of the most hazardous pieces of foundry equipment, or they can be one of the safest. It is highly desirable that grinding wheels be properly mounted and periodically checked by competent supervisors. Most every foundry has some grinding equipment, or some grinding practice which violates the AMERICAN STANDARDS ASSOCIATION *"Safety Code."* There should be at least one man in the grinding department who is familiar with this *"Safety Code,"* since these rules are very fair and represent the best information obtainable on this important subject.

Part 2—Cost Comparisons*

AIR BARRELS VS. AIRLESS BARRELS

15. Prior to 1937, all of the medium sized (10 to 70 lb.) production castings produced in our foundry were cleaned in sand blast barrels. This process was slow and inefficient, in that a great many castings had to be "spot" blasted after being milled. When all of the various costs of cleaning by this method were carefully compiled such as cost of labor, power, air, supplies, maintenance, etc., the total was $3.96 per ton of castings cleaned. Realizing that this was a very high figure, we studied the situation with the result that airless barrel equipment was installed to do this work. We have since cleaned in excess of 30,000,000 lb. of castings by this newer method. The figures tabulated below represent a summary of our actual operating costs compiled over a four year period:

	Per Ton
Cost of labor (operation and maintenance)	$0.70
Cost of repair parts, supplies and power	0.86
Total operating cost	$1.56

As well as saving $2.40 per ton of castings cleaned, this equipment produces cleaner castings which not only look better but are cheaper to machine.

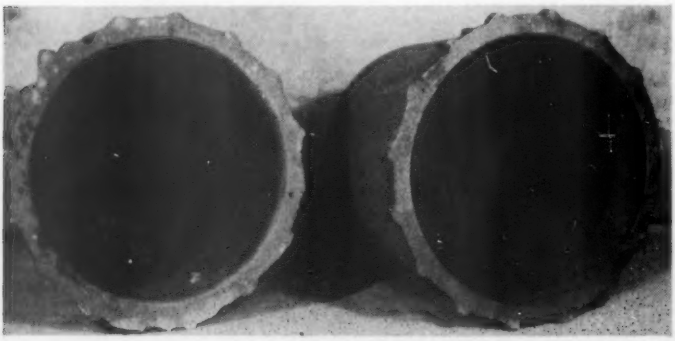

FIG. 2—AIR RESERVOIR CASTINGS. (LEFT) ROUGH CASTING. (RIGHT) CASTING CLEANED BY BLASTING.

* The cost figures quoted in this paper are based on the labor rates and the material costs prevailing in our plant. They should not be considered as representing an average for this type of work.

TUMBLING VS. AIRLESS BLAST CABINET

16. Among the castings which we make is an air reservoir which is shown in Fig. 2. This casting is about 19-in. high by 19-in. in diameter, while the thickness of the side walls is about 5/16-in. When this job which weighs 120 lbs. was first made it was cleaned in a sand blast room. This was costly, since production was low, and the sand blast was not strategically located.

17. Because we had several tumbling mills available, we tried tumbling to relieve the bottle neck. Our earlier methods along this line were very discouraging due to the relatively thin walls which made mill breakage excessive. We later found, however, that by packing the castings in the mills with small logs, we were able to reduce breakage to about 1 per cent.

18. It so happened that after this job had been running for some time, we were called upon to check over cleaning facilities to determine our ability to handle a new type of casting which was being contemplated for the foundry. This checkup, which covered the relative efficiency of all production cleaning jobs, showed that it was costing us more than we thought to clean the reservoir casting as:

	Per Casting
Direct labor cost	$0.055
Shot cost	0.007
Power cost	0.035
Belt and maintenance cost	0.032
Mill breakage loss	0.042
Total cleaning cost	$0.171

19. We consulted the manufacturers of airless cabinets who assured us that by using their machinery we could clean this casting considerably cheaper than the above quoted figure of $0.171 per casting. After carefully checking their bids and estimates against the experience of others who were already using this type of equipment, we advised our management to the effect that we would recommend the immediate purchase of such a machine to be used for standard existing production work, without waiting until such a time as the contemplated new job was started. Some time

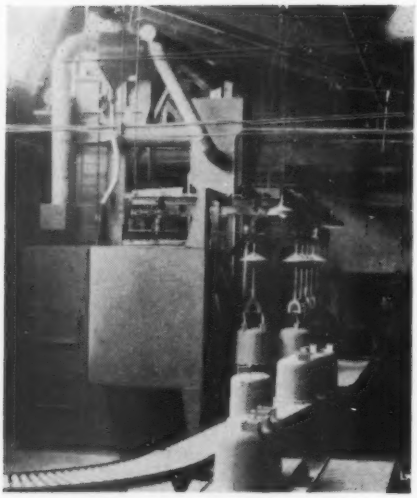

FIG. 3—AIRLESS BLASTING CABINET SHOWING ARRANGEMENT FOR PUTTING CASTING INTO AND TAKING OUT OF MACHINE.

later the airless cabinet shown in Fig. 3 was installed in a location convenient to the reservoir hot storage floor.

RESERVOIR CLEANING CYCLE DESCRIBED

20. After the gates and some of the sand has been knocked from the reservoir castings, they are picked up in groups of five with a mono-rail electric hoist and deposited on the roller conveyer which feeds the cleaning machine loading device as shown in Fig. 4. This loading device consists of a short movable section of roller conveyer equipped with an air hoist that raises the castings up into hooking position. Because of this handling equipment, and the convenient location of the indicator gauges and controls, only one man is necessary for the complete operation of the machine.

21. After blasting, the castings move down the roller conveyer which may be switched to feed any one of three processing tracks. The castings are first tipped bottom up onto a bench for inspection and gauging. After the inspection the reservoirs travel to the next man who rolls them from the conveyer into a chuck for chipping. After being chipped and ground, the castings are conveyed to the tester who, with the aid of an air hoist, drops them onto a hydraulic test machine where they are subjected to a pressure of 240 lb. per sq. in. After completing the operation, the tester loads the castings

onto specially constructed trailer trays for delivery to the machine shop.

IMPROVEMENTS NOTED

22. Our present reservoir castings are much cleaner than they ever were when using tumbling, breakage loss is practically nonexistent and our operating costs are much lower as:

	Per Casting
Labor cost	$0.018
Abrasive cost	0.045
Power	0.006
Maintenance	0.015
Total	$0.084

or a gain over the old method of .083 per casting.

23. We also clean the 110 lb. cylinder casting shown in Fig. 5 and the 40 lb. reservoir partition casting shown in Fig. 6 in the same machine and by these same general methods. When the operating gains for all of the jobs thus cleaned were carefully compiled, it was found that the investment in the installation will be self-amortizing in considerably less than a year.

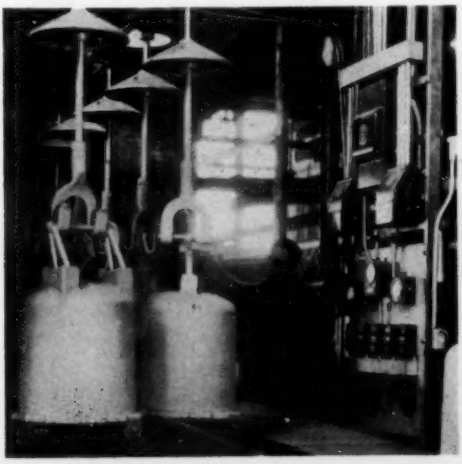

FIG. 4—AFTER GATES AND SOME OF THE SAND HAS BEEN KNOCKED FROM THE RESERVOIR CASTING, THEY ARE PICKED UP IN GROUPS OF FIVE WITH A MONO-RAIL ELECTRIC HOIST AND DEPOSITED ON A CONVEYOR WHICH FITS THE CLEANING MACHINE LOADING DEVICE.

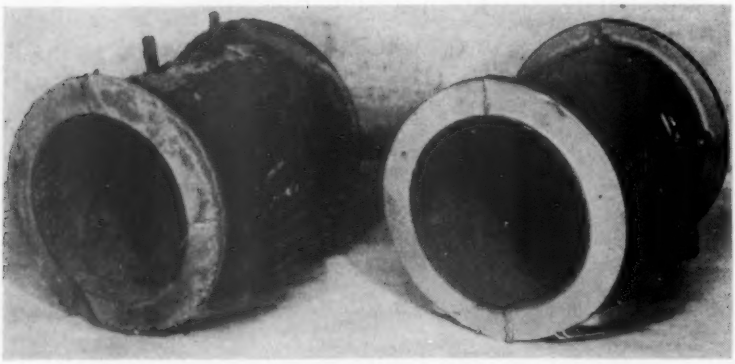

FIG. 5—110 LB. CYLINDER CASTING SHOWING A ROUGH AND A CLEANED CASTING.

CONCLUSIONS

24. We are usually forced to study our cleaning problems in order to overcome some chronic trouble, or because of some change in casting design or foundry output. Whenever such problems are encountered, it is a good plan to take a broad view of the whole cleaning program, past, present and future. When this approach is made with the thought in mind that a well cleaned casting, free from burrs and fins, possesses excellent sales appeal, carefully planned cleaning equipment, though expensive in first cost, may prove well justified.

25. Such investments in our case have not only given excellent returns but have resulted in improving the appearance of the product, which is not only desirable but virtually a necessity on defense work.

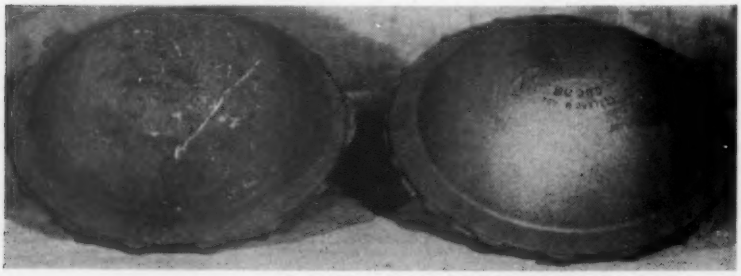

FIG 6—40 LB. RESERVOIR PARTITION CASTING SHOWING A ROUGH AND A CLEANED CASTING.

DISCUSSION

Presiding: JAMES THOMSON, Continental Roll & Steel Foundry Co., East Chicago, Ind.

Co-Chairmen: W. R. JENNINGS, John Deere Tractor Co., Waterloo, Iowa.

E. W. BEACH, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

MEMBER: How do you arrive at the amount of shot?

MR. NYE: In order that the proper amount of shot may be fed to the wheels, the shot control is set so that a maximum current reading is obtained. We found on the cabinet machine that, while the wheel motors might draw a possible 25 amps. without overload, the maximum shot load obtainable was about 22 amps. If there is too much shot, the reading will fall off; if there is too little shot, it will also fall off. The experienced operator can look at the ammeter and tell whether he needs a little more shot or a little less. To summarize, the shot feeds are set by the ammeter readings.

CO-CHAIRMAN BEACH: Have you had any experience with the various special grades of shot in contrast with standard commercial grades? Are the castings you are cleaning straight gray iron?

MR. NYE: We clean some steel forgings and some bronze and brass castings. In regard to shot, in our paper we stated that the cost for abrasive is 4½ cents per reservoir casting. That is a very high figure. We tried all varieties, from No. 25 down to as low as No. 14, and we found that the smaller the size, the less the consumption. However, if it is too far on the fine side, the castings have a rough appearance, whereas, when using the coarser shot, many barnacles, etc., are knocked off in the cleaning machine. We finally standardized on the No. 17 shot. Mr. Beach, as you have both types of equipment, I would be interested in your experience.

CO-CHAIRMAN BEACH: We use the standard commercial products.

MR. NYE: Have you ever used any annealed shot?

CO-CHAIRMAN BEACH: I can not give you the definite data, but, on our product, it did not show sufficiently better results to warrant using the processed shot.

MEMBER: Have you any comparative cost figures on shot compared with a water blast carrying either sand or another abrasive, or plain water?

MR. NYE: No. I would like to express a personal opinion about that. I have seen that type of equipment working and have checked a number of cost sheets on it. In any airless cleaning equipment of the centrifugal type, the abrasive is one of the biggest costs. Our conclusions were that, for our particular types of castings, water blasting did not seem to be very well suited. The best applications I have seen of water blasting have been on very large castings. I have no complete data at hand on this question.

MEMBER: Is that cleaning spread adjustable?

MR. NYE: There are different numbers of blades in the different

makes of wheels and what is called a control cage in the center. It is a round cylinder with a slot opening in the side. The shot comes down the feed spout to the wheel where the impeller picks it up and distributes it through the slot in the control cage to the blades of the wheel. The control cage can be adjusted so that the slot is in different positions, which in turn affects the pattern of the wheel. In general, any adjustment is accomplished by moving the control cage around to change the pattern to throw in one direction or the other. As a rule, sizes are pretty well worked out to balance with the capacity of the feed pipes in order to get the maximum efficiency out of the wheel. The shot can be patterned with a steel plate or with a casting. There are two or three ways of doing it. The control can be adjusted and run for a few seconds, after which time the pattern is outlined by the amount of heat that is in the casting. The hot spot locates the center of impact intensity.

MEMBER: Is there any place a distance away from the blades where there is greater efficiency?

MR. NYE: In general, these machines are patterned for maximum efficiency at about 36-in. from the wheel itself. I am not well versed enough in this particular phase of airless equipment design to go into detail on this particular point. However, on any that I have ever seen, work is usually cleaned at a distance of from 2 to 3 ft. from the wheels.

MEMBER: I have just purchased one. There are two wheels revolving in opposite directions toward the center through which the work passes.

MR. NYE: Are the two wheels concentrating on the same point?

MEMBER: Yes.

MR. NYE: They can be controlled to a surprising degree. The pattern can be set within 2- or 3-in. It can be set to an almost definite line of demarcation as to where the blasting is to stop and where it is to begin. At about 3 ft. away from the wheel, the pattern, as a rule, is from 3½ to 4 ft. in length.

MEMBER: We locate ours with a plywood back drop.

MR. NYE: That would be a good way. We usually use a piece of steel plate.

CHAIRMAN THOMSON: I have heard some criticism on the cost of running those machines because of the expense of the blades, etc. Can you tell us anything about that?

MR. NYE: The blades are expensive. If anyone were to quote on the cost per hour of running a machine of this sort, other methods might seem cheaper. That is true on the basis of cost per hour. However, when the production of one of these machines is considered, it offsets the relatively high operating cost. The biggest detriment to any foundry airless cleaning machine is sand in the abrasive. If the foundry has a good separation system, whereby all the sand can be taken out of the abrasive, the wear parts will last ten times longer than when sand contaminates the abrasive. We make a cast iron valve body which weighs about 65 lb. When this casting comes out of the mold it has about 60 lb. of core sand entrapped in the core passages, and when we put it into the airless mill just as it came from the knockout, we got only 10 hours

from a $20.00 set of wheel wear parts when running this job. We tried pre-tumbling for about 15 min., rolling it over in a barrel to remove the excess sand before running it in the airless barrel, to see what the effect would be. We got 100 hours of blade life, about ten times as much as before. A good clean abrasive means everything to low maintenance costs. If any one has a machine of this type, try scooping up a handful of feed shot, and, if it contains a fair percentage of sand, the separator, ventilation or method should be checked. It is bound to be causing excessive wheel wear. In foundries running annealed mallable castings, steel castings after heat treatment, or work of that sort, wheel life is a matter of months, not of hours. In foundry work, the biggest detriment to efficient operation is dirty shot.

CHAIRMAN THOMSON: Is it not the function of the manufacturer of the machine to provide sufficient ventilation, etc. for that?

MR. NYE: Yes. However, since conditions are different on nearly every job, the manufacturers do not hit the mark every time.

MEMBER: What blade life are you getting?

MR. NYE: We average about 100 hours. This time is checked by means of an electric timer. On a continuous operating machine, where heat is a factor, there is not that much blade life. We are using an improved type of blade where we formerly used an older type which was thinner and did not have nearly that much life.

CO-CHAIRMAN BEACH: Have you tried making your own blades?

MR. NYE: We tried that, but we never had much success.

CO-CHAIRMAN BEACH: Did you try chilling?

MR. NYE: We tried everything we could think of without much success.

MEMBER: I understand that you have a curve of cost between the air and airless barrel. What percentage of difference did you find on the tonnage basis?

MR. NYE: Our cost with air barrels was $3.96 per ton complete with air, power, labor, maintenance, supplies, etc. These cost figures are based on labor rates and material costs prevailing in our plant, and should not be considered as representing an average for this type of work. Using an airless barrel, our cost for labor, including the operation and maintenance, is 70c per ton. Our cost for repair parts, etc., is 86c per ton, giving a total cost of $1.56 per ton with airless equipment as compared with $3.96 per ton for the older type.

MEMBER: On what comparative basis is the cost of air per hour? How do you base that on the cubic foot consumption?

MR. NYE: A ¼-in. nozzle uses about 103 to 104 cu. ft. of free air per min. at 100 lb. pressure per sq. in. The book of trade standards adopted by the COMPRESSED AIR INSTITUTE gives the cost of air at 6c per 1000 cu. ft. at 100 lb. pressure per sq. in. We checked that and found that ours was 5.6c per 1000 cu. ft. at 90 lb. pressure per sq. in. Therefore, the cost of operating a ¼-in. nozzle at 100 lb. pressure per sq. in. is about 54c per hour. In the old type of barrel, the finish is nice and they do a good job, but the cost is quite high. In the barrels we formerly had, we had four nozzles in a row in each of three groups, and as they rolled

around, each set blasted through a certain degree of angularity. We had two compressors released for other service when we took our air barrels out. When it is put on an hourly basis, four good sized nozzles blasting all the while add a great deal to the cost of cleaning.

I have talked mostly about sand removal. However, in the paper, I went into some detail on grinding wheels. There are a couple of details in this regard that I believe are worth stressing. One thing very often seen is grinding equipment that runs at improper speed, either over speeded which is very dangerous, or under speeded which is very costly. I would like to quote from the book "*Grinding Wheels and Their Uses*," published by the GRINDING WHEEL MANUFACTURERS' ASSOCIATION. "Tests show that the time taken per cut at 16000 surface ft. per min. is only ⅛ as much as that taken at 4000 surface ft. per min., and that the wheel wear is only ⅓ as great at the higher speeds."

This shows that it is very important to get the right wheel speed. It is possible to get about 30 per cent more useful life out of your wheels with a multiple speed machine as compared with a single speed machine. If anyone is thinking of buying a grinder, it is very important to get a machine which will not only do the job, but do it efficiently as well. I am very enthusiastic about multiple speed equipment. I was in a foundry a while ago when they were mounting some new wheels. They did not ring test them. The operator stood in front of the newly mounted wheels and threw the belt on. It made me nervous because I have seen wheels break. I want to stress the fact that the AMERICAN STANDARDS ASSOCIATION publishes a "*Safety Handbook*" which is available without charge. It is a good pamphlet. It is not too conservative, and it tries to be as fair as possible in its approach to every grinding problem. I think that there should be at least one man in every grinding department who is familiar with this code. It is a serious thing to have a grinding wheel break.

CHAIRMAN THOMSON: How much time is lost in these snagging grinders where there are 3 sets of pulleys on changing belts?

MR. NYE: Ten or fifteen minutes. Changing the belts is not a hard job. It does add a lot to the usability of the wheel. Based on checks made shortly after we installed some multiple speed grinders, we found that we formerly used only 668 cu. in. of abrasive out of 1500 cu. in. of new wheel. After we installed the multiple speed grinders, we were able to get about 1000 cu. in. of useful wear from a wheel.

MEMBER: Do you change your speeds on the 1- or 2-in. basis?

MR. NYE: We start off at 24-in., and we change at 20-in.

MEMBER: We change on a basis of 2-in. Did you have any experience in comparing the rubber bonded wheel and the silica bonded wheel?

MR. NYE: The elastic bonded wheel, because it can be run at higher speeds, is more efficient and cuts faster. Machine maintenance is higher, but I do think that the speed of the cut offsets the higher maintenance, and the other objections to it, such as, for instance, its burning odor. I do not think, in our particular case where we have a number of medium speed grinders now in use, that it would ever pay to buy a lot of new equipment just to get the extra speed of cut.

Training Sanity During the Emergency

By D. F. Lane*, Sparrows Point, Md.

Abstract

In this paper the author explains the general apprentice set-up of the Bethlehem Steel Company, covering the scope, qualifications of applicants, selection of applicants, probationary period, apprentice training schedule, assignment of work and progress record. He gives several reasons for the continuation and expansion of training programs and tells what would be lost if regular apprenticeship was abolished under the stress of emergency problems. He then gives, in an appendix, a detailed analysis of the work schedule, suggests tools for foundry apprentices, and shows the shop work rating card used in his company, together with an explanation of the rating system used.

1. Today American industry is faced with the most gigantic production expansion program that has ever confronted any nation. Vast numbers of ships, tanks, guns and airplanes must be produced in the shortest possible time if we are to remain a free people.

Meeting the Demands of War Production

2. The War Production Board has informed us that millions of new workers must be trained and other millions of present employees must be taught higher skills. At the present time, there are about 5½ million people employed in war industries. When our production program achieves its full stride, some 23 to 25 million people will be employed in the production of various war commodities.

3. We have been told that at least 90 per cent of all training must be done right on the job by foremen, assistant foremen, and experienced workers, and that almost 40 per cent of this work is strictly skilled. Skill of a higher order is required because of the need for interchangeability of parts. No matter who makes the parts, or in what section of the country they are made, when a bat-

* Director of Training, Bethlehem Steel Co.

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tery of anti-aircraft guns requires new tubes or barrels, each must fit exactly—there is no time to fit or adjust them later.

4. To take advantage of America's vast producing capacity, every small industrial establishment will have to participate in some phase of the war effort. In many instances, the small manufacturer may not be able to completely produce a war product because of industrial limitations. It may be that only a fraction of a war product can be produced at one plant, necessitating the product to be sent to one or more plants before it is finally converted into a useful war commodity. Where such products must be farmed out to other plants, it is most essential that they be machined or processed to exacting limits. Otherwise great difficulty and confusion will result when the product is being assembled. Apprenticeship, in many respects, will provide the higher skills that are necessary to meet the demands of war production.

THE IMPORTANCE OF APPRENTICE TRAINING

5. Through the farsightedness of the management of Bethlehem Steel Company, training programs have been maintained for many years at its various plants to insure a constant supply of semi-skilled and professional personnel. These programs are being intensified continuously to meet the demands of war production.

6. The training program at the Sparrows Point plant has been custom built around the needs of the organization. Its objectives are to provide skilled operators, skilled mechanics, potential foremen, supervisors, draftsmen and to train college graduates who in the future will be eligible for advancement to responsible positions.

7. In view of the fact that the above training programs have been in operation over a period of years and have satisfactorily yielded trained personnel to take their respective places in our steel producing plant, these programs are being expanded rather than curtailed during the emergency.

APPRENTICE TRAINING PROGRAM

8. The Sparrows Point plant of Bethlehem Steel Company manufactures, among other things, pig iron, brass and iron castings, blooms, billets, slabs, rails, all types of plates, sheet bars, steel strip, skelp, wire, wire rods, strand, nails, and all types of cargo-carrying vessels.

9. Since approximately 20 per cent of all the employees working in the steel plant are more or less engaged in maintaining the steel producing facilities, apprenticeship programs have been set up so as to insure an adequate supply of skilled craftsmen.

10. To attract high grade young men for permanent employment in the various trades embraced within the scope of the company's activities, an organized program of apprentice training was inaugurated many years ago to give new employees systematic training on the job as well as related technical instruction in the classroom.

11. The major purpose of the training program outlined here is to provide a well-rounded training and education in the practical and theoretical phases of certain occupations for the young men employed as apprentices by the company. The attainment of this major purpose should be gained through associations and procedures that encourage and develop good citizenship, pride in craftsmanship and economic stability.

12. In all of the shops where apprentices are engaged, a definite plan of training has been worked out so that when an apprentice completes his trade he will have explored it to its fullest extent, thus producing a versatile craftsman. Several years ago, an analysis was made of all trades, breaking them down into their component parts, such as operations, processes, skills, tools and related information. From this, lists were made on which apprentices may check their diversity of operations and skills as they progress through the stipulated learning period.

13. A skilled worker should be intelligent and well-informed and should possess a high degree of adaptability. To develop this type of a man, it is necessary that the apprentice be given related technical and general instruction. In the first place, this will give him such technical knowledge as cannot be made available during regular working hours. Second, it will impart to him a knowledge of industry and society that will enable him to become a good worker as well as an intelligent citizen. In addition to developing the technical and general knowledge necessary for intelligent and efficient employment, such an apprentice's instruction has emphasized the importance of keeping up-to-date with current technical information.

14. Summing up, it might be said that the aim of the company is to provide an opportunity for ambitious young men to receive systematic training and instruction suited to their individual abil-

ities, inclinations and education, so that their productivity and value may be developed to the fullest extent; also, to create a large group of broadly trained, skilled, loyal and intelligent mechanics for service in the plant, from which foremen, supervisors and other members of the supervisory force may be recruited from time to time.

Scope

15. The scope of the present program is confined to the following trades in which apprentices are indentured: Blacksmith, brick laying, carpentry, coppersmith, electrical, foundry, locomotive repair, machinist, machinist (outside), machinist (electrical), pattern, pipe, roll turning, sheet metal, structural iron worker, tool and die making.

Qualifications of Applicants

16. It is mandatory that all applicants for apprenticeship shall have passed their eighteenth birthday but not yet passed their twentieth birthday.

17. The applicant is required to have completed the tenth grade of the public school system, or its equivalent. However, present practice limits consideration to high school graduates who have satisfactorily completed the following subjects: 1 year of algebra, 1 year of geometry, 1 year of mechanical drawing, 1 year of trade practice, 1 year of general science.

Selection of Applicants

18. Perhaps the greatest problem confronting those engaged in personnel work is that of selecting new employees. To make the selection more objective, all applicants for the past several years have been subjected to a comprehensive examination, to determine their academic fitness for apprenticeship. The examination includes the following subjects: English, drawing, geometry, mathematics and general science.

19. The applicant is not selected on a basis of the examination alone. His high school record is taken into consideration as well as his rank in his graduating class. If the high school record and test score are above 70 per cent, the applicant is given a shop interview by the general foreman of the trade in which he is most interested. This presents him with the opportunity to look the shop over and to ask any questions pertaining to it. If he receives a favorable rating from the general foreman, the applicant is granted a

further interview with the superintendent of the division. If the superintendent feels that he possesses all the potentialities necessary for apprenticeship, he approves the application and returns it to the training division, where it is placed on the eligible list. It remains there until such time as there is a call from that particular shop. Then applicants are selected accordingly.

20. When the applicant presents himself for employment, his health and general fitness are determined by a medical examination by a company physician.

Probationary Period

21. An applicant who has been tentatively accepted for apprenticeship training, is required to serve a probationary period of 500 working hours, or approximately 3 months. During this time, he receives the regular course of class and shop instruction, and his aptitude and fitness for his chosen trade are observed carefully. At the expiration of the probationary period, the training division and the head of the shop department jointly determine the desirability of continuing the applicant in the training course. All applicants who have been approved, together with their parents, enter into an apprenticeship agreement with the company, whereupon they become duly qualified apprentices.

Apprenticeship Period

22. The apprenticeship period is considered as having started with the beginning of the probationary period and continues for the full term, in accordance with the terms of the agreement, unless earlier terminated as therein provided.

23. The regular period of apprenticeship is 8000 hours, or approximately 4 years. Applicants for apprenticeship training may be admitted into the shop course any time during the year. However, they are admitted to classroom work only during the months of September and February.

24. No advance credit for shop training or classroom training is given to any applicants, but they are required to begin with the first tasks and demonstrate their ability to perform them satisfactorily.

Schedule of Training

25. The training and instruction of apprentices in the shops follow a regular schedule of tasks and duties. Apprentices are ad-

vanced from one task to another as rapidly as their attainment of skill and proficiency may warrant. They are under the direct supervision of a shop instructor or apprentice foreman.

26. Each apprentice receives 4 hours of classroom instruction per week. This is broken up into two 2-hour classes a week, which last for the duration of the semester. The first semester starts in September and ends on the last of January, while the second semester starts on the first of February and continues until the last of June. In other words, the apprentice is given 10 months of classroom instruction covering the technical side of his trade.

27. All technical instruction is developed and administered by the apprentice school staff. The apprentice school is not associated with any outside educational agency. The courses are presented by part-time instructors who are journeymen mechanics or engineers selected from our own organization because of their trade proficiency and ability to teach. Many of the instructors hold college degrees.

28. Courses of study covering the 4-year term have been developed by the shop instructor of each trade, together with the supervisor of apprentices. Each course is approved by the department head of each trade.

29. Table 1 shows a schedule of processes* that foundry appren-

Table 1

SCHEDULE OF PROCESSES FOR FOUNDRY APPRENTICES

	Months
Core Shed	5
Floor—Helping	3
Physical Laboratory	2
Side Floor	6
Chemical Laboratory	2
Bench Molding	5
Pattern Shop	2
Machine Molding	3
Sand Conditioning and Testing	2
Brass Foundry	3
Office Routine	1
Cupola	2
Machine Shop	2
Main Floor Work	10
	48

* For detailed information on schedule of processes see Appendix, p. 527.

tices follow in the shop and Table 2, the curriculum covered in the classroom.

Table 2

CLASSROOM CURRICULUM FOR FOUNDRY APPRENTICES*

September to January	February to June
1st Year	
2 hrs. Blueprint Reading	2 hrs. Mechanical Drawing
2 hrs. Foundry Practice	2 hrs. Foundry Practice (con't)
2nd Year	
2 hrs. Practical Shop Mathematics	2 hrs. Practical Shop Mathematics
2 hrs. Pattern Making	2 hrs. Pattern Making (con't)
3rd Year	
2 hrs. Machinery's Handbook	2 hrs. Machinery's Handbook
2 hrs. Advanced Foundry Practice	2 hrs. Advanced Foundry Practice
4th Year	
2 hrs. Metallurgy	2 hrs. Advanced Metallurgy
2 hrs. Industrial Economics	2 hrs. Foremanship

Apprenticeship Certificate

30. Upon satisfactory completion of the apprenticeship training course, the apprentice is awarded the standard size certificate (14x17-in.) as well as a billfold certificate (2½x4-in.) which certifies to his length of service and training and to his qualifications as a full-fledged journeyman in his chosen trade. At the completion of 8000 hours, each apprentice receives a substantial bonus. Incidentally, this bonus is in addition to the pay the apprentice receives throughout the course.

Assignment of Work

31. When the apprentice has finished his period of orientation in his trade, he is then assigned to a particular type of work. The kind of work to which he is assigned depends upon his previous experience and education. However, every effort is made by the general foreman to place the apprentice in the type of work for which he is best adapted by experience, skill and interest. A few graduate apprentices are placed in departments other than those in which they had been trained, either because of the need of such

* Each course is given 2-hours per week.

departments or because of their interests and qualifications. Recently a number of graduate apprentices have been placed in engineering departments throughout the plant.

Progress Record

32. After the apprentice has been assigned to a particular type of work fitting his abilities and aspirations, he is given a reasonable amount of time to make good and to progress on the job. Every 6 months, a progress record card is sent out from the training division to the general foreman of the various departments employing apprentices, asking for information relative to their interest, attitude, workmanship and potential growth. These progress records give quite an accurate check on the career of a graduate apprentice. This information is very helpful in ascertaining the upgrading of qualified employees for subsequent advancements.

EXPANSION OF TRAINING PROGRAM

33. We, at the Sparrows Point plant, are, at the present time, continuing and expanding our apprenticeship program for the following reasons:

(1) Due to the increased activity of industry it is difficult, or next to impossible, to secure skilled mechanics except by apprenticeship. It is accepted by all at our plant that an apprentice with a year or more of apprenticeship is far better qualified than any mechanic obtainable through the employment office.

(2) In view of the fact that most of the work in the maintenance shops at Sparrows Point is of a jobbing nature, that is, two jobs seldom alike, it is most essential that the working force consist of versatile craftsmen of the highest type. Apprenticeship is the only means of securing such mechanics during the present emergency.

(3) For the past 10 years, the Sparrows Point plant has been continuously expanding its steel-producing facilities. As these facilities are increased, the maintenance departments must expand in equal proportion, which calls for additions to the skilled force. The skilled mechanics necessary have been made available through long-range apprenticeship.

(4) To effectively produce versatile craftsmen who can handle any job flowing through the shop, regardless of

origin, it is desirable that the craftsman shall have had some experience and training pertaining to the source of such jobs. This can only be made possible by means of a flexible apprenticeship program. At the Sparrows Point plant, all apprentices are assigned to the various steel-producing departments for specified periods, varying in length according to the trade and its relationship to the producing unit.

(5) During the emergency, it is becoming difficult to secure a high-grade, well-balanced individual. However, where carefully-planned, long-range apprenticeship programs exist, such as at the Sparrows Point plant and elsewhere, many outstanding young men will be attracted to apprenticeship because of the opportunities offered. Some of these opportunities are:

(a) An attractive starting rate—most industries no longer penalize apprentices while learning a trade.

(b) A graduated wage scale providing for a substantial increment every 2,000 hours.

(c) Opportunity to explore every technical process and skill in any particular craft.

(d) Opportunity to continue one's education beyond high school. Technical information is offered during the work day which, in many cases, is comparable to curricula in colleges or universities.

(e) A more regular employment.

(f) A certificate upon completion of the course.

(g) A broad educational foundation which later promises reasonably continuous employment and opportunities.

(h) Opportunities for serving the country in the first line of defense during the present emergency.

(6) Apprenticeship at the Sparrows Point plant is not only designed to add to the supply of craftsmen required for industrial expansion, but also to replenish the normal "turn-over" in the trade resulting from retirement, illness, death, transfers or the upgrading of craftsmen to other fields of employment.

(7) From a cost standpoint, apprenticeship more than pays for itself over a period of time. Where apprenticeship is organized on a sound basis, the results in productive efforts far exceed the initial cost of setting up supervisory and clerical personnel to administer the program. Apprenticeship at Sparrows Point is distinctly a paying proposition.

(8) We, at the Sparrows Point plant, are proud of the fact that over a period of years our apprentice turnover has been less than 3 per cent. We have had few malplacements brought to our attention. Once an apprentice is carefully examined and selected, he is placed in a craft of his particular choosing and exposed to the schedule of shop processes and classroom work. Most of the boys meet this challenge and give forth their best efforts to successfully complete the graduated tasks before them. Apprenticeship tends to stabilize employment.

(9) The present industrial expansion program has necessitated additional numbers of supervisors, foremen, technicians, lead men, etc. At the Sparrows Point plant, many of these positions have been filled by people who have served a four-year apprenticeship.

It has been our experience that the man who has been thoroughly trained in the fundamentals and manual skills of a particular craft has developed a methodical approach when called upon to interpret objectively, analyze and reason. When a man has had experience in taking something apart, and putting it together again with his hands, he can usually do it in his mind. When he can do it successfully in his mind, he is also able to direct the efforts of other people.

(10) Industry is constantly changing regardless of economic conditions. When one occupation goes out, another comes in. The demand for skilled workers persists, and the person who has acquired all the basic skills of one occupation can more easily and quickly acquire the new or additional skills of another occupation.

When the emergency is over, industry is going to need men with ability and vision. The trained man who has graduated from a sound apprenticeship program will do much to solve the problems of the future.

EFFECTS OF ABOLISHING APPRENTICESHIP

34. Should our regular apprenticeship be abolished under the stress of emergency problems, we would be compelled to forego many distinct advantages which are of utmost importance at the present time.

(1) With apprenticeship abolished, the lower standards would make it difficult to secure the same caliber individuals to carry on the work.

(2) Elimination of apprenticeship would cause increased spoilage, rejects, and accidents and excessive wear and tear on equipment. Production would be greatly retarded and costly inspection inescapable. Costs in general would have a tendency to rise.

(3) If single-purpose men were utilized in place of general mechanics there would be an additional increase in labor turnover.

(4) Where a corps of single-purpose men take the place of versatile craftsmen, a greater number of men will usually have to be employed. In a jobbing shop where work is so diversified and where so many operations require a high degree of skill, many more people would be needed because, over a limited period of time, each could develop only a small fraction of the total skill required. A number of persons, each possessing a small degree of skill, would be needed to take the place of one all-around mechanic. The single-purpose man is generally not as stable a worker, and this also adds to the number of men employed.

(5) Additional supervision would be required in trades where apprenticeship was abolished in favor of single-purpose men, due to the greater number and lower quality of the men.

(6) When a person is not grounded in the basic fundamentals of his job, he is likely to lack the confidence to go ahead with his work. Where this occurs, the supervisor likewise loses confidence in the workman.

(7) During the apprenticeship period, the apprentice is rotated from job to job and operation to operation. He discovers that there are certain things that he can do best. Upon completion of his apprenticeship, he might spe-

cialize in this one phase of the work. If apprenticeship were abolished, many latent abilities would not be discovered.

(8) Eliminating apprenticeship, we feel, would greatly impair the future growth of potential foremen, supervisors, general foremen, technicians, etc.

(9) After the emergency, it would be difficult to absorb large numbers of limited craftsmen and single-purpose men. The permanency of such a man's tenure would be conditional.

(10) If apprenticeship was abolished by my company and finally became extinct on a national basis, it would only take a generation before many of the basic fundamentals of a craft would be lost forever. This would undoubtedly have a marked effect on our national social status. Apprenticeship is the only means of perpetuating the industrial skills of the past.

(11) Substituting single-purpose men for apprentices or skilled craftsmen in shops that have in the past been traditionally apprenticed, would, to my mind, greatly reduce the morale of such shops.

35. For all of these reasons, elimination of apprenticeship is inconceivable. Abolishing apprenticeship at the present time would court disaster. Instead of curtailing, we should all encourage its expansion. Skill is the key to production.

AMERICA'S PRODUCTION PROBLEM AND APPRENTICE TRAINING

36. American industry has attained world leadership because of its ability to produce. American industry is today confronted with the greatest production problem that was ever conceived by man. The only way we are going to defeat the Axis Powers is to produce in a short time more than what it took them 9 years to produce.

37. Good sound apprenticeship programs will greatly hasten our accomplishing that fact.

38. According to the American Iron and Steel Institute and the War Production Board, there has been an average increase in iron and steel castings from 45 to 50 per cent since 1938. Just what the increase will be in 1942, 1943 and 1944 nobody knows. The foundry industry should take on more apprentices and start apprenticeship

programs. The sooner America's forces have superiority in equipment, the sooner will come ultimate peace.

Appendix

FOUNDRY SHOP

In the foundry shop the apprentice is required to observe shop regulations and safety rules. A booklet of safety rules is issued and these rules are explained by the various shop foremen. The apprentice must attend various safety meetings.

Leggings and goggles must be worn by the apprentice while handling or working around hot metal. The apprentice is cautioned never to stand under suspended loads. The proper method of handling hot metal and the use of metal skimmers are pointed out.

The apprentice is taught Safety First and that a clean orderly shop promotes safety, makes the job easier and eliminates lost motion.

SUGGESTED TOOLS FOR APPRENTICES IN FOUNDRY

1—6 ft. rule
1—Hammer
3—Trowels
1—Brush
1—Level
1—Pair of pliers
1—Rapping bar
3—Draw screws
4—Lifters
1—Flange tool
2—Pipe tools
1—Button tool
3—Slickers
4—Hub tools
1—Double-end tool
1—Wet bulb
1—Set of flask pins
1—Gate gutter
1—Rub
1—Bellows
1—Bosh or swab
1—Monkey wrench
1—Riddle or sieve
1—Shovel
1—Set of wedges
2—Pairs of clamps
1—Strike
1—Set of calipers—inside and outside

SCHEDULE OF PROCESSES

Core Shed—5 months

1. Apprentice is given safety talk by foreman.
2. Apprentice is taught how to operate core oven.
   a. Keep fire.
   b. Observe
      (1) Baking time.
      (2) Baking temperature.
3. Charging core oven.
4. Unloading core oven.
5. Delivering cores to proper job.
6. Learning core sand mixtures.
   a. Small cores for gray iron.
   b. Small cores for brass.
   c. Large cores for brass.
   d. Large cores for iron.
   e. Cores for aluminum.
7. Core binders.
   a. Purpose.
   b. Kinds.
      (1) Clay.
      (2) Oils.
      (3) Cereal.
   c. Proportion.
8. Operating core machine
   a. Stock cores.
      (1) Cut size.
      (2) Black.

9. Making small cores on bench.
   a. How to vent core.
      (1) Wire.
      (2) Wax.
   b. Use of core plates.
   c. Use of core driers.
   d. Reinforce core with
      (1) Nails.
      (2) Rods.
      (3) Wires.
   e. Proper ramming of core.
   f. Pasting cores together.
   g. Blacking cores.
10. Helping coremaker on floor.
   a. Mixing core sand.
   b. Placing arbor, rods and bars.
   c. Ramming cores.
   d. How to vent large cores.
   e. Placing lifting hook.
   f. Preparing core plates for core.
   g. Black cores.
   h. Sweep large cores.
11. Making arbors for cores.
   a. Laying out arbors in bed.
   b. Placing lifting hook.
   c. Pouring arbors with cupola iron.

Floor—Helping—3 months

1. Safety rules.
2. Assembling material for job.
   a. Pattern.
   b. Flask, cope, drag and cheek.
   c. Gate stick.
   d. Facing sand.
   e. Back up sand.
   f. Parting.
   g. Runner box.
   h. Anchors.
   i. Weights.
   j. Sea coal for blacking.
   k. Gaggers, rods, nails, etc.
   l. Glay wash.
   m. Vent pipe and charcoal.
   n. Molasses water.
3. Equipment and how to use it.
   a. Flask.
      (1) Cope.
      (2) Drag.
      (3) Cheek.
      (4) Mold board.
      (5) Bottom board.
   b. Gaggers.
   c. Nails.
   d. Rods.
   e. Anchors.
   f. Lifting plate.
   g. Arbors.
   h. Chaplets.
   i. Shovel.
   j. Riddle.
   k. Hand rammer.
   l. Pneumatic rammer.
   m. Clamps and wedges.
   n. Molders tools.
4. Observing and helping in the following operations for both simple and complicated molds:
   a. Bed in patterns.
   b. Face molds.
   c. Ram molds.
   d. Rap patterns.
   e. Draw patterns.
   f. Cut gates.
   g. Dress mold.
   h. Place cores.
   i. Methods of venting mold and core.
   j. Closing the mold.
   k. Calculate weight required to hold cope.
   l. Build runner box.
   m. Pouring operation.
   n. Drying molds.
   o. Making and pouring open sand molds.

Side Floor—6 months

1. Assemble material for the following jobs:
   (see floor work—2)
   a. Simple one piece patterns.
   b. Simple one piece pat-

terns with simple core.
c. Simple parted patterns.
d. Simple parted patterns with simple core.
e. Oil strainer body.
f. Housing.
g. Bearing bottoms.
h. Bell mouths.
i. Rolls.
j. Fittings.
(1) Cross.
(2) Tee.
(3) Ell.
(4) Y.
k. Aprons.
l. Furnace doors.
m. Grate bars.
n. Ascension pipe for coke oven.
o. Pistons.
p. Barrels.
q. Gears.
r. Manifold.

Bench Molding—5 months

1. Simple pattern.
   a. Flat back.
   b. Bushings.
   c. Split patterns.
2. Use of match plates.
3. Placing cores and anchors.
4. Use of nails to reinforce mold.
5. Methods of gating and risering.
6. Proper use of the swab.
7. Dressing the mold.
   a. Patching broken places.
   b. Black mold with plumbago.
   c. Place cores and vent.
   d. Cut gate at proper place.
   e. Proper size of gate.
8. Effect of head on the casting.
9. Proper weight to hold down cope.
10. Pouring operation.
    a. Pouring temperature.
    b. Rate of pouring.
11. Defects caused by improper pouring.
    a. Washes.
    b. Mis-runs.
12. Improper pouring temperature.
    a. Burnt on sand.
    b. Shrinks.
    c. Porous castings.

Machine Molding—3 months

1. Squeezer and draw machine.
   a. Mechanics of the machine.
      (1) How constructed.
      (2) How to operate.
      (3) Name and use of each part.
      (4) Oiling system.
   b. Mount plate on machine.
   c. Filling flask with sand.
   d. Squeeze.
   e. Rap and draw.
   f. Dress mold.
   g. Use of the snap flask.
   h. Pouring molds.

Sand Conditioning and Testing—2 months

1. Requirements of a molding sand.
   a. Permeability.
   b. Bond.
   c. Refractory.
2. Chemical analysis.
   a. Silica.
   b. Alumina.
   c. Ferric oxide.
   d. Lime.
   e. Magnesium.
3. Sand tests.
   a. Permeability.
   b. Screen analysis for grain fineness number.
   c. Clay content.
   d. Green sand strength.
   e. Moist content.
   f. Dye absorption test.
   g. Sintering test.

4. Re-claiming sands.
5. Facing sand mixtures.
6. Core sand mixtures.

Office Routine—1 month

1. Time keeping.
2. Orders.
3. Shipment of castings.
   a. Weight of each.
   b. Quantity shipped.
   c. Charge to proper account.

Cupola—2 months

1. Safety rules.
2. Observe the following operations:
   a. Clear drop.
   b. Repair lining.
   c. Make bottom.
   d. Light.
   e. Charge.
   f. Melting.
   g. Tapping metal.
   h. Tapping slag.
   i. Bott to stop flow.
3. Information.
   a. Iron-coke ratio.
   b. Blast pressure.
   c. Blast volume.
   d. Coke in bed.
   e. Height of bed charge.
   f. Pounds of iron per charge.
   g. Melting ratio.
   h. Calculate charge from known pig iron analysis.
   i. How to alloy with nickel, chromium and molybdenum.

Main Floor Work—10 months

1. Study of sections and uses of product.
2. Equipment necessary for molding.
3. Molding — green — dry and skin dry.
   a. Gating.
   b. Risers.
   c. Placing cores.
   d. Securing cores.
   e. Closing.
   f. Weighting (method of figuring).
   g. Pouring.
   h. Shake out.
   i. Chipping and cleaning.
4. Inspecting (cause of defects).
5. Shipping (including proper loading).
6. In this period, special effort should be made to learn the most suitable compositions and elements necessary for each job.

Physical Laboratory—2 months

1. Safety rules.
2. Assorting test bars according to
   a. Heat number.
   b. Test number.
   c. Customer number.
   d. Grade of material.
   e. Type of test.
      (1) Yield point.
      (2) Tensile stress.
      (3) Elongation.
      (4) Reduction.
      (5) Bend test.
      (6) Brinell test.
3. Milling machine (observing and operating).
   a. Type of work.
      (1) Mounting specimen.
      (2) Cutting parallel surfaces on tensile test specimen.
      (3) Milling samples for chemical tests.
4. Drill press (observing and operating).
   a. Type of work.
      (1) Drilling for chemical tests.
      (2) How to sharpen drills.

5. Power saw (observing and operating).
   a. Preparing specimen for tests from large samples.
6. Shaper (observing and operating).
   a. Preparing specimen from burned test bars.
7. Bend test machine (observing and operating).
8. Universal grinder (observing and operating).
9. Surface grinder (observing and operating).
   a. Grinding for etching.
10. Tensile test machine (observing and operating).
    a. Type of work.
       (1) Preparing specimen for machine.
          (a) Obtaining cross-sectional area.
          (b) Marking specimen for elongation.
       (2) Mount specimen.
       (3) Apply load.
       (4) Reading the load.
          (a) Yield point load.
          (b) Maximum load.
          (c) Measuring broken specimen for elongation and reduction.
       (5) Calculating data.
          (a) Yield point.
          (b) Tensile stress.
          (c) Elongation.
          (d) Reduction of area.
11. Brinell machine (observing and operating).
    a. Preparing specimen.
    b. Applying load.
    c. Reading and recording data.

Chemical Laboratory—2 months

When apprentices are assigned to the laboratory, they are first instructed in the preparation of iron and steel samples for analysis. Such sampling includes the drilling of open-hearth pit tests, preliminary steel tests and cast samples from blast furnace. They are instructed as to manner of pouring these tests, type of mold, etc., suited to mechanical sampling. An effort is made to describe the various types of steels and pig irons and their production and properties. This description must of necessity be very brief.

Having had some practice in sampling, the apprentices are then assigned as helpers to analysts and learn the routine analytical control of usual elements in iron, as silicon, sulphur, phosphorus, manganese, etc., as well as analysis of blast furnace slags. They are encouraged to correlate analysis of metal with furnace temperature, slag composition, etc. While so employed, they become familiar with the nature of alloying elements found in irons and usual ranges of compositions.

When this assignment is completed, they are given an opportunity to experiment with analysis of brasses, bronzes, and white metal alloys. In this work, they become familiar with the general compositions of lead base and tin base babbitts, bearing and other bronzes and form some idea as to uses for which these alloys are intended.

Pattern Shop—2 months

1. Learn safety rules.
2. Pattern woods.
   a. Kiln-dried.
   b. Air-dried.
   c. Wind.
   d. Warp.
   e. Names.

(1) Sugar pine (soft).
(2) Cherry (hard).
f. Measurement.
(1) Board foot.

3. Glue.
a. Source.
b. Preparation.
c. Care.
d. Use.

4. Shellac.
a. Source.
b. Preparation—red, yellow and black.
c. Care of shellac and brushes.
d. Use.

5. Other materials used.
a. Sandpaper.
b. Chalk.
c. Nails.
d. Screws.
e. Putty.
f. Wax.
g. Leather fillets.
h. Corrugated fasteners.

6. Hand tools:
a. Names and uses of:
(1) Saws.
(2) Planes.
(3) Chisels.
(4) Gouges.
(5) Brace and bits.
(6) Squares.
(7) Bevels.
(8) Rules.
(9) Marking gage.
(10) Dividers.
(11) Trammel.
(12) Calipers.
(13) Hammer and mallet.
(14) Screw driver and awl.
(15) Pliers and clamp.
(16) Wood files.
(17) Oil stones and slips.
(18) Fillet irons.
(19) Nail set.
(20) Bench knife.
(21) Spoke shave.

7. Power tools—method of driving.
a. Name, use of, observing operator and operating the simple machines.
(1) Jointer.
(2) Planer.
(3) Band saw.
(4) Circular saw.
(5) Lathe.
(a) Face plate.
(b) Cylindrical.
(6) Sander.
(a) Disk.
(b) Spindle.
(7) Dowel pin machine.
(8) Band saw sharpener.
(9) Core box machine.
(10) Drill press.

8. Pattern colors.
a. Machine surfaces.
b. Un-machined parts.
c. Core prints.
d. Stop off.
e. Seats for loose pieces.

9. Use of drawings.
a. Stock allowance.
b. Shrinkage.
c. Draft finish.
d. Simple construction.
e. Placing core prints.

Brass Foundry—3 months

1. Learn safety rules.
a. Attend safety meetings.

2. Floor molding (assisting molder).
a. Green sand molding.
(1) Proper flask.
(2) Location of gate.
(3) Facing sand.
(4) Back-up sand.
(5) Ramming drag and cope.
(6) Drawing pattern.
(7) Dressing mold.
(8) Placing core.
(9) Clamping mold.

SHOP WORK RATING CARD B.S.Co. _____ Plant

Name _____ Check No. _____

Dates: From _____ to _____

Job or Machine _____ Hours _____

Foreman _____ Shift _____

Rating for Period Covered by this Card

Rating Points	Rating
1. Speed	
2. Accuracy	
3. Confidence	
4. Attitude	
5. Judgment	
6. Economy	
7. Safety	
8. Set-up	
AVERAGE	

4 = 100 per cent - Outstanding

3 = 90 per cent - Excellent

2 = 80 per cent - Good

1 = 70 per cent - Poor

0 = 60 per cent - Failure

SHOP WORK RATING CARD

Speed —Working rate of doing a job.

Accuracy —Quality of exactness, correctness or precision in which work has been done.

Confidence —The degree of assurance or belief entrusted to a person to carry a job through to completion.

Attitude —The state of mind a person is in due to his interest, behavior or conduct and how these traits affect his work, superiors, etc. Ability to cooperate with others.

Judgment —The faculty of determining the correct procedure to follow on a job. This is usually based on past experience and education.

Economy —Practical systematic operation of tools and equipment. Elimination of waste.

Safety —The condition of setting up a job or actual participation on the job which is absolutely free from any danger.

Set-Up —The state of preparation or fixing of materials, job or equipment to be later processed.

(10) Pouring mold.

b. Skin dry mold.
   (1) See 2 a.
   (2) Applying heat to face of mold.

c. Dry sand molding.
   (1) See 2 a.
   (2) Drying the mold.
      (a) Gas torch.
      (b) Oven.

d. Methods of gating.
   (1) Top gate.
   (2) Bottom gate.
   (3) Pop gate.
   (4) Horn gate.
   (5) Whirl gate.

3. Mixing metals.
   a. Virgin metals.
   b. Scrap of known analysis.
   c. Using both a and b.

4. Observing melting equipment.
   a. Electric furnace—direct-arc.
   b. Oil-fired, open-flamed.

c. Tilting crucible.
d. Stationary crucible.

5. Observing cleaning equipment.
   a. Chipping.
   b. Grinding.
   c. Abrasion cut-off.
   d. Washing.
6. Definition of foundry terms.

Machine Shop—2 months

1. Safety rules.
2. Helping on large planer.
   a. Flat horizontal machining by having head square with table.
   b. Setting head to a given angle.
   c. Flat horizontal machining by use of two heads.
   d. Vertical machining by use of side head.
3. Helping on vertical boring mill.
   a. Drilling.
   b. Boring.
   c. Reaming.
   d. Cylindrical turning.
   e. Facing.
   f. Recessing.
4. Helping on horizontal boring mill.
   a. Drilling and spot facing.
   b. Boring.
   c. Reaming.
   d. Tapping.
   e. Horizontal and vertical facing.
   f. Recessing.
   g. Fly cutting.
5. Observing machine and operator.
   a. Shapers.
   b. Slotters.
   c. Lathes.
   d. Millers.
   e. Gear cutting machines.
   f. Grinders.
6. Simple jobs on bench, floor and drill press.
   a. Flanges.
   b. Stanchions.
   c. Brass bushings.
   d. Filing edges on gear teeth.
   e. Jig drilling.

DISCUSSION

Presiding: C. J. FREUND, University of Detroit, Detroit, Mich.

Co-Chairman: J. G. GOLDIE, Cleveland Trade School, Cleveland, O.

C. C. ADAMS[1]: I want to compliment Mr. Lane on the wonderful improvement that he has made in the employees of our foundry. Every boy he has placed there has been a great improvement over those turned over to us during the last 20 years.

MEMBER: Do you have a written agreement with your apprentices?

MR. LANE: Yes.

MEMBER: Do you pay your apprentices for class work?

MR. LANE: Yes.

MEMBER: Can an agreement with an apprentice be broken after the probation period?

MR. LANE: We can terminate the agreement if the work is not up to standard. If an apprentice feels that he would be more interested in getting into some other trade or craft, or can prove to us that he can

[1] Bethlehem Steel Co., Sparrows Point, Md.

take advantage of a job in some other company, we do not stand in his way.

The agreement, as far as we are concerned, is purely psychological. In the past 3 months, four or five apprentices have been brought to my attention who were considering termination and going elsewhere, but before they had finally made up their minds, their parents had become informed and influenced them to remain with the company.

V. G. CORNELIUS[2]: Have you had any experience with trade certification tests? If your apprentice program is a total of 8000 hours, divided into units of 2000 hours each, do you have any way of certifying the apprentice's ability to go on with the next 2000-hour period by either written or oral test or examination of some type?

MR. LANE: Yes, apprentices are graded every month in the shop. With respect to classroom studies, apprentices are graded every week, or at least once a month. We maintain a check both in the shop and in the classroom. There is quite a high degree of correlation. The boy who does not do well in the classroom usually does not do well in the shop and vice versa.

MR. CORNELIUS: Regarding your statement that you start apprentices in September and in February, does that mean an apprentice who starts, for example, on March 15 does not get the advantage of any classroom work until the following September?

MR. LANE: Yes.

S. F. LEVY[3]: Do you take high school graduates as apprentices?

MR. LANE: Yes. We have an examination that we administer to all prospective apprentices. Anybody who can make a grade of 75 per cent or better on this examination is eligible to serve an apprenticeship. Thus far, I have never seen anybody who did not graduate from high school make a grade of 75 per cent or better.

MR. LEVY: Is classroom instruction that the apprentices get part of their working time or after working hours?

MR. LANE: It is during the regular 8-hour work day.

MR. LEVY: Is the shop instruction considered part of the job?

MR. LANE: Yes. In many cases the instructor on the job is also utilized in the classroom.

MR. LEVY: From your experience, what kind of training would you say boys need most?

MR. LANE: I would say, in general, prospective apprentices lack a good foundation in drawing and mathematics.

MR. LEVY: I believe that checks with the experience that we have had. We find that boys, even high school graduates, sometimes are quite deficient in arithmetic, especially common fractions.

F. W. HUNTER[4]: What percentage of the apprentices starting in your foundry remain with you to complete their course? What percentage of those who complete the course remain to become a permanent part of the organization?

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[2] Carnegie-Illinois Steel Co., Chicago, Ill.
[3] Black-Clawson Co., Hamilton, Ohio.
[4] Sargeant and Co., New Haven, Conn.

MR. ADAMS: Since Mr. Lane has been with us, we hold one hundred per cent of our apprentices.

MR. HUNTER: That is remarkable. How do you find the type of young man and the interest you get today compare with a few years ago?

MR. ADAMS: One hundred per cent better.

T. M. BOST, JR.[5]: Do you take boys out of the shop and place them in your apprentice program?

MR. LANE: Yes.

MR. BOST: What is their starting rate if their former rate was above the regular apprentice starting rate?

MR. LANE: They would have to begin at the apprentice starting rate, regardless of their former rate.

MR. BOST: Do you always bring them back to the regular starting rate?

MR. LANE: Yes, regardless of past experience. Our starting rate is high enough to be attractive, and many times it is a promotion to get into the apprentice school.

V. J. SWANSON[6]: What methods do you use in teaching industrial economics to the boys?

MR. LANE: In teaching industrial economics, we use Kimball's text entitled "*Industrial Economics.*" However, we also use about 30 other texts for supplementary reading. It is mandatory that all apprentices purchase their own textbooks when we use a text. And we have used Kimball's book as a guide.

I have been very fortunate in being able to get heads of departments to come in and talk to apprentices enrolled in the industrial economics class. When we take up a section on planning, I usually get the general shop foreman of the Mechanical Department to come in and give an hour's talk. Every effort is made to make the course of instruction practicable, acquainting the apprentices with many of the fundamental principles of economics upon which the company operates.

J. H. BROWN[7]: How do you get your apprentices?

MR. LANE: I believe the greatest advertising we have is within the plant. We have endeavored to put our apprenticeship program on a high plane. For your information, 12 per cent of all the apprentices that we have enrolled have had at least one year of college, and about 3 per cent have had 2 years of college. We have maintained excellent cooperation with the Baltimore city and county schools. This is one source in which most of us have been weak in the past. We have sat in our offices and thought that all the outstanding boys were going to come to us. I spend two or three afternoons every month going to the various schools and giving talks on apprenticeship opportunities. The biggest problem most of us are confronted with is that people do not know what we have to offer.

MR. BROWN: In Canada, there is a very serious labor shortage in every line. The young men who are material for apprenticeships are going into

[5] Lynchburg Foundry Co., Lynchburg, Va.
[6] Foreman Training School, Rock Island Arsenal, Rock Island, Ill.
[7] Brown-Boggs Co., Ltd., Hamilton, Ontario, Canada.

the army or into machine shops, running single-purpose machines where the money and bonus is high, and they are not interested in foundries.

MR. LANE: I believe this depends, to a certain extent, upon the starting rate apprentices receive. In our particular plant, we have found that the starting rate is an important factor. Perhaps you might have better results if you made your starting rate more attractive. No apprentice is subject to bonus for the first 2000 hours. After that, there is an increment every 2000 hours. In practically all the shops, the contract or bonus system is used so the apprentice is granted an opportunity to increase his earning power beyond that of his base rate.

WAYNE STETTBACHER[8]: How does the hourly starting rate of an apprentice compare with the hourly earning he might hope to get as an unskilled worker in the foundry? If the apprentice was formerly employed as an unskilled worker in the foundry, and then decided to become an apprentice, how much of a sacrifice does he make?

MR. LANE: We start all of our labor at the same rate.

MR. STETTBACHER: There you have an advantage. There is another point that comes to my mind in respect to selling apprentices and parents of apprentices on the idea of the boy sacrificing 4 years of time and effort. The mention of the shipbuilding industry suggests to the average layman that, in times of peace or depression, shipyards are idle. Do you manage to maintain such a degree of constancy in your employment as to impress the public generally that an apprentice who goes into a trade in the shipyard is going to have reasonably constant employment, year in and year out?

MR. LANE: Yes, because our foundry takes care of both the steel and the shipyard and, should our shipyard become curtailed with the additional expansion that probably will take place in our steel plant, we will be able to give reasonably steady employment to molders in the foundry.

MR. STETTBACHER: You are very fortunate in that respect. The boys in Detroit are not interested at the present time. The opportunities are too great for them to go into defense plants and get jobs as ordinary workmen on the strength of their present efficiency. Apprentice material is being sought right now, even in boys less than eighteen years old.

CO-CHAIRMAN GOLDIE: What percentage of your foundry apprentices are high school graduates?

MR. LANE: One hundred per cent.

CO-CHAIRMAN GOLDIE: We are finding it hard to get high school graduates to go into the foundry. We have had a great deal of success in a foundry with boys who have had less than a high school education; who have taken high school training after finishing their apprenticeship.

What percentage of the boys in your foundry have fathers who are molders there?

MR. ADAMS: In my foundry, I do not have a boy whose father is a foundryman.

CO-CHAIRMAN GOLDIE: I believe Mr. Lane's foundry is one of the few

[8] Employers Association of Detroit, Detroit, Mich.

in the country where the boys are one hundred per cent high school graduates.

MR. ADAMS: We did not enjoy that advantage until recent years.

JOHN GRENNAN[9]: Do you take the applications and put them on file?

MR. LANE: We have a waiting list. We do not have any trouble getting boys.

MR. GRENNAN: How long is the wait?

MR. LANE: I have found in the past 6 months that when a likely looking boy comes along, we go out of our way to create an opening right away. But we interview six, eight or, perhaps, a dozen boys every day. The more promising boys are employed as soon as there is an opening. This may be a few days or weeks.

MR. GRENNAN: Is there an abundance of material?

MR. LANE: Yes. I think we are quite fortunate in that there are a number of excellent schools in Baltimore and the vicinity from which to draw.

MR. GRENNAN: If you had a prospective opening in sight, would you make any attempt to take care of the boy from the time he makes application until the opening occurs?

MR. LANE: Yes, we would. However, we have an agreement with other companies in Baltimore not to take an employee who is working for another war production plant.

MR. GRENNAN: Do you use as an inducement to enter apprenticeship the fact that most of the young men will go beyond the skilled trade, as a trade, and get into executive positions?

MR. LANE: Absolutely.

MR. GRENNAN: Do you have figures to show what percentage of your boys do fill these executive positions, rather than stay in the trade for which they originally trained?

MR. LANE: I do not know what the percentage is. That is an excellent question, and I shall look it up. Practically all of our general foremen and many or most of our foremen have served their apprenticeship at our particular plant. I would like to go a step further and say that we have a few superintendents and assistant superintendents who have served their apprenticeship in our particular plant.

It is quite evident that there is a great reservoir of opportunities present that an apprentice can aspire to. When it can be pointed out that the general shop foreman who has charge of all mechanical shops served an apprenticeship, it looks pretty good to a boy. He becomes interested and registers a sincere desire to become an apprentice.

[9] University of Michigan, Ann Arbor, Mich.

Progress Report— Comparison Data on the Durability of Naturally-Bonded and Synthetic Molding Sands by the Repeated Pour Test†

By Jack CoVan*, Urbana, Ill.

Abstract

The durability of molding sands may be determined by several methods. The method which has been recognized as giving durability values that compare favorably with foundry practice is the repeated-pour test. This test requires considerable time for its performance. The object of this investigation was to determine basic data on the durability of five selected molding sands by the repeated-pour test. These data are to be used in a later investigation as the basis for comparing durability values determined on the same molding sands by other methods which require less time to perform. They will also serve as a guide to future investigations for the purpose of finding a rapid and reliable laboratory method for determining the durability of foundry sands. The durability values presented in this paper were ascertained by determining the quantity of clay necessary to maintain each molding sand at a constant green compression strength. The five molding sands were suggested by the American Foundrymen's Association Foundry Sand Research Committee's Subcommittee on Durability as being representative of the different types, as used commercially. Data on three synthetic and two naturally-bonded sands are included. The repeated-pour test method was used by C. M. Nevin at Cornell University in 1925[1]*, and at present is considered the best method of determining values that compare favorably with foundry practice.*

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†This paper compiled from thesis submitted for Master's Degree in Mechanical Engineering. Work done in cooperation with Subcommittee on Durability, A.F.A. Foundry Sand Research Committee.

*Graduate Student, University of Illinois.

[1]Nevin, C. M., *"The Life of Molding Sand,"* Transactions, American Foundrymen's Association, vol. 33, pp. 763-796 (1925).

Note: This paper was presented at a Sand Research Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 22, 1942.

HISTORY OF DURABILITY INVESTIGATIONS

1. The problem of durability of sands is not new. Reports of work to determine that property extend back over the past 18 years or more. Although the repeated-pour test method is accepted as the best method at present, it is a long and laborious process. As a result, a continual search is progressing for a shorter method of ascertaining the durability of molding sands.

2. The three most important methods used by previous investigators are briefly stated in the following paragraphs.

Repeated-pour Test Method

3. The repeated-pour test method used by Nevin[1] is performed by tempering a specimen of sand to optimum working condition and testing it by the standard A.F.A. bar test for green strength. Then a test mold is rammed with this sand. The cavity in the test mold is cylindrically shaped and the ratio of the weight of metal contained in the cavity to the weight of sand is such that the strength of the sand is reduced by a practical amount each time molten metal is poured into the test mold.

4. After the mold is prepared and molten cast iron is poured into it, the casting is allowed to cool to room temperature. The casting is then "shaken-out" and is brushed or scraped free of sand. The entire amount of sand is then remixed, and water again is added to temper the sand to optimum working condition. The standard A.F.A. bar test is repeated for the green strength. The cycle is started again with the ramming of the second test mold. This procedure is repeated for ten times or "heats." A decrease in green strength of more than 20 per cent is said to indicate a sand with undesirable durability.

Oven Test Method

5. The determination of durability of molding sands by heating samples in an oven was suggested by H. W. Dietert[2]. The object of this method is to obtain the green strength of the sample of molding sand after it has been tempered to optimum working condition. The sample of molding sand is then heated in an oven to 800°F. for 2 hours and then cooled to room temperature. After retempering to optimum working condition, the test for green strength is made, and the results are compared with the original green strength of

[2] Dietert, H. W., and Wakefield, Jr., H. W., *"Sand Control in the Foundry,"* TRANSACTIONS, American Foundrymen's Association, vol. 34, pp. 244-268 (1926).

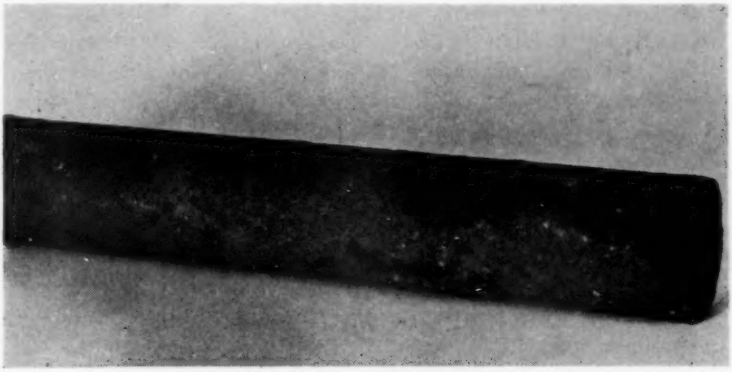

FIG. 1—CAST SPECIMEN.

the sand to determine the percentage loss in breaking strength. This procedure is repeated, raising the temperature of the oven in increments of 200°F. until a temperature of 1400°F. is reached.

Dehydration and Rehydration of Bond Method

6. A weighed sample of the molding sand, previously tempered to best workable moisture and tested for green compression strength, is placed in a pan and baked in an electric oven at 200°F. for 4 hours. After baking, the specimen is removed from the oven and allowed to cool to room temperature and is then reweighed. The gains or losses in weight are recorded. The specimen of molding sand is again placed in a pan and heated in an oven to 800°F. for one hour. It is removed from the oven, allowed to cool to room temperature, and weighed. Losses due to dehydration of the dry bond are recorded.

7. The specimen is then tempered to optimum working condition and green compression strength tests are made. The loss in green compression strength is compared to the original green strength test. After the green strength test, the sand is dried in an electric oven for 4 hours at 200°F., removed, and allowed to cool to room temperature. It is weighed, and gains or losses in weight are recorded. The cycle described is repeated on the same sample increasing the temperature at 200°F. intervals from 800 to 1400°F. At 1400°F., in addition to determining the loss in weight due to dehydration at 1400°F., the total loss of weight of the sand is determined.

8. Tests performed by Nevin[1] included all of the three methods

previously described. In 1936, the University of Illinois Engineering Experiment Station published a bulletin [3, 4] which recorded the results of an investigation by Professors Casberg and Schubert which attempted to correlate the durability of foundry molding sands as obtained by the same three methods. Results of this investigation, briefly, were as follows:

1. That it is not possible to predict accurately the life of a molding sand by any of the three methods.

2. That the amount of bond necessary to bring a given quantity of molding sand back to its original green compression strength depends entirely on the kind and nature of the bonding material.

3. That the durability of a molding sand depends upon the physical and chemical properties of the mineral, or minerals, found in the bonding substances.

3Casberg, C. H., and Schubert, C. E., *"An Investigation of the Durability of Molding Sands,"* University of Illinois Engineering Experiment Station Bulletin, no. 281, vol. 33, no. 34, April 21, 1936, pp. 1-54.

4Schubert, C. E., *"A Correlation of the Physical and Chemical Properties of Clays with the Durability of Molding Sands,"* TRANSACTIONS, American Foundrymen's Association, vol. 45, pp. 661-690 (1937).

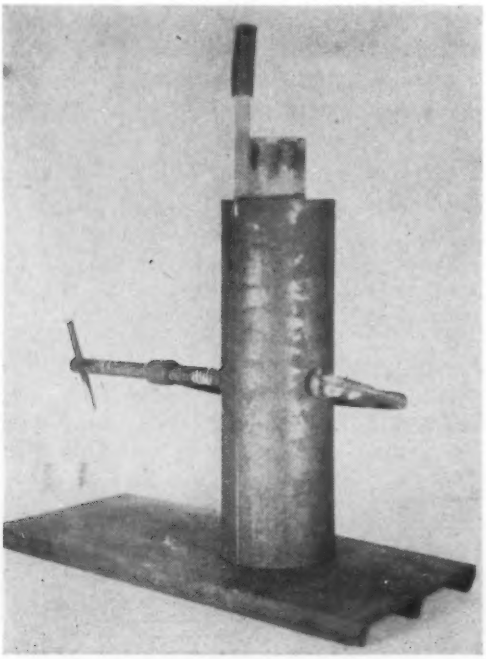

FIG. 2—EQUIPMENT FOR RAMMING TEST MOLD WITH SPLIT FLASK.

Table 1

FINENESS TESTS OF SILICA SAND

Screen Mesh	*Per Cent Retained* — *Trial 1*	*Trial 2*
6	0.00	0.00
10	0.00	0.00
20	0.00	0.00
28	0.00	0.00
35	0.65	0.70
48	17.56	16.98
65	43.81	42.28
100	29.68	30.69
150	6.30	6.94
200	1.11	1.40
270	0.00	0.42
Pan	0.23	0.31
Total	99.34	99.72

9. As a result of these findings, the A.F.A. Foundry Sand Research Committee's Subcommittee on Durability realized that no acceptable values of durability for definite specimens, as determined by the repeated-pour test method, existed. These values are necessary as a basis of comparison and reference if a rapid and reliable laboratory method is to be developed. This subcommittee also recommended that the method of performing the repeated-pour test be changed to make it conform more closely to foundry conditions.

10. Thus, it was at the suggestion of the Subcommittee on Durability of the A.F.A. Foundry Sand Research Committee that this investigation was made.

MATERIALS USED AND TESTS MADE

Materials Used

11. The materials used in the tests were supplied by members of the American Foundrymen's Association in sufficient quantities so that future additional tests can be made, if necessary. The materials supplied may be divided into two groups: (1) the naturally-bonded molding sands, and (2) washed and dried silica sand and three types of clays for making the synthetic molding sand mixtures.

12. Two natural sands were supplied in the same condition as they are delivered to industry. One of these sands was an Eastern and the other was a Midwestern naturally-bonded molding sand.

The composition and strength of these were as follows:

(a) The Eastern sand, as received, had a green compression strength of 16.9 lb. per sq. in. at 4.4 per cent moisture. For clay content and fineness data, see Table 2.

(b) Midwestern sand, as received, had a green compression strength of 24.9 lb. per sq. in. at 4.1 per cent moisture. For clay content and fineness data, see Table 3.

13. The materials supplied for synthetic molding sands consisted of: (a) A silica sand of the Ottawa type, whose fineness tests are shown in Table 1; (b) a montmorillonite clay, as used commercially; (c) an illite clay, as used commercially; and (d) a kaolinite clay, as used commercially.

Tests Made

14. Throughout the investigation, tests were made in accordance with the standardized procedure contained in "*Testing and Grading Foundry Sands and Clays—Standards and Tentative Standards,*" published by the American Foundrymen's Association Foundry Sand Research Committee. The following tests were made: (1) Fineness, (2) A.F.A. clay, (3) green compression strength, and (4) dry compression strength.

METHOD OF PROCEDURE

15. The fineness of both the silica sand, used in the synthetic sand mixtures, and the naturally-bonded sand was determined.

Table 2

FINENESS TESTS OF EASTERN NATURAL MOLDING SAND

Screen Mesh	*Per Cent Retained*	
	Trial 1	*Trial 2*
6	0.66	0.46
10	0.87	1.40
20	2.14	2.14
28	2.46	2.94
35	2.10	4.52
48	10.20	10.91
65	17.67	17.32
100	29.42	28.03
150	12.84	12.47
200	3.90	4.05
270	.72	.82
Pan	1.09	1.48
Total	84.07	86.54
A. F. A. Clay, per cent	13.12	13.12

Table 3

FINENESS TESTS OF MIDWESTERN NATURAL MOLDING SAND

Screen Mesh	*Per Cent Retained* — *Trial 1*	*Trial 2*
6	0.00	0.13
10	0.60	0.35
20	1.94	1.38
28	2.94	2.24
35	5.34	4.81
48	12.80	11.36
65	17.65	17.84
100	17.69	18.72
150	8.35	9.32
200	5.10	5.71
270	1.90	9.44
Pan	7.91	0.67
Total	82.22	81.97
A. F. A. Clay, per cent	17.59	17.27

The green compression strength of samples of the naturally-bonded sand, tempered to an arbitrary figure of approximately 4 per cent moisture, also was determined. This is the green compression strength of what will be referred to in this paper as the "raw natural molding sand."

16. One of the conditions set forth for this investigation was that the green compression strength be held constant. It was decided that each sand used in the repeated-pour test should possess an original green compression strength of 6 lb. per sq. in., as such a strength compared favorably with foundry practice. Since the raw naturally-bonded molding sands tested approximately three times this strength, it was necessary to lower the strength by adding washed and dried silica sand to these sands and mix them until a green strength of 6 lb. per sq. in. was reached. Thus, a proportion of weight of silica sand to weight of raw naturally-bonded molding sand was determined which would give approximately the required strength.

Tempering Procedure

17. The amount of moisture present in the tempered sands, as well as the method of tempering the samples, was standardized. The method of tempering that was adopted was briefly as follows: The specimen to be tempered (naturally-bonded molding sand and silica sand or silica sand and clay) was placed in a muller-type sand mixing machine and mixed for 2 min. For the next 2 min., the moisture was added continuously to the mixture by conducting

the water from a container to the point of mixing through a small copper tube. After the water was added, mixing was continued for three min., making a total mixing time of 7 min. The specimen was then collected, riddled through a No. 6 riddle or screen, and placed in tightly stoppered glass bottles to temper for 24 hours.

18. The amount of moisture to be used with each sand was determined by preparing a number of specimens of the two naturally-bonded molding sands with approximately 6 lb. per sq. in. green compression strength. Each of these specimens was tempered with a different per cent of moisture. At this point, a group of three experienced molders examined the specimens without knowing the moisture content of any sample. After "feeling" the sand, each man voted for the sand that he thought was at the best working or molding condition. In this way, a moisture content was selected as being the optimum working condition for each specimen and that moisture percentage was maintained constant throughout the investigation.

19. Preparation of the synthetic molding sand specimens consisted of adding various amounts of clay to silica sand and mixing in a muller-type mixing machine until a green compression strength of 6 lb. per sq. in. resulted at the best workable moisture, as determined by the "feel" method.

Preparation of Test Samples

20. Specimens of the two natural molding sands with silica sand added, weighing 3000 grams, were mixed with the proper amount of water and allowed to temper 24 hours in tightly stoppered glass bottles. In the same manner, the specimens of the three synthetic sands were prepared, using 3000 grams of silica sand and the necessary amount of clay.

21. The Subcommittee on Durability decided to include one additional sample of each of the five molding sands (three synthetic and two natural) containing one per cent more moisture than the tempered samples through the first three heats of the test to see if there was any indication that excessive moisture had any effect on the durability of the sand. Throughout the tests, these samples will be referred to as the wet specimens.

Molding Procedure

22. After the ten samples had been tempered in the glass bottles for 24 hours, they were tested for moisture, green compression

strength, and dry compression strength. Each sample was then rammed to make a test mold. The pattern used was 2-in. in diameter by 11-in. long. A cylindrical flask, open at both ends, was used. The inside diameter of the flask was 3⅝-in. and the length was 12-in. These dimensions gave a weight ratio of approximately one part of sand to two parts of iron. This ratio produced sufficient loss in strength in the sand each time metal was poured into the mold.

23. The test mold was rammed in the following manner: The flask or tube was placed upright on a flat metal plate and one-inch of sand was rammed in the bottom of the flask. The pattern was placed in the center of the tube, and the sand was gradually rammed around it. Each layer of sand was rammed with a stick ⅜-in. square by 18-in. long, and with a uniform number of strokes as nearly equal in force as possible. The ramming continued until the top of the flask was reached. The mold was "struck off," and the pattern rapped to loosen it from the sand, after which it was drawn from the mold. The finished mold was covered with a metal sprue cover and set aside to await pouring. To avoid excessive moisture loss, molten gray iron was poured into the molds 45 min. after the molds were made.

Melting Procedure

24. The cast iron used in pouring the test molds was melted in a gas-fired, crucible-type furnace. The charge in the first three heats consisted of 125 lb. of metal of which 50 per cent was scrap and 50 per cent was pig iron. In the last seven heats, the five molds required 65 lb. of metal containing the same scrap to pig iron ratio.

25. After the charge of iron reached a satisfactory molten condition and temperature, it was removed from the furnace, skimmed, and poured into the test molds. The molds were allowed to cool to room temperature, were "shaken-out," and the sand was brushed from the castings with a stiff wire brush, care being taken to collect all the sand from each mold.

Procedure for Maintaining Green Compression Strength

26. The sand from the mold was put in the mixing machine and mixed with that part of the specimen that had not been used in the mold. Water was added, in accordance with the 7 min. mixing procedure previously described. After the sample had been mixed the required 7 min., it was tested for moisture content. Due to

the fact that there was some loss of moisture from the time the specimen was in the machine until it had tempered in the glass bottle for 24 hours, it was necessary to set a moisture percentage somewhat above the final desired moisture. When the results of the moisture tests were satisfactory, the green compression strength of the sample was determined. The results of the green compression strength test showed whether it was necessary to add more clay or new naturally-bonded molding sand to the samples to maintain the original green compression strength of 6 lb. per sq. in.

27. If more clay or new naturally-bonded molding sand was required, it was added to the sample. This usually required the addition of more water. When these additions were made, the material was mixed for an additional 5 min. and another set of moisture and green compression strength tests were made. After tempering for 24 hours in tightly stoppered glass bottles, the moisture and green compression strength tests were repeated. If the results were satisfactory, the sample was ready to repeat the cycle of preparing the test mold.

Number of Pourings

28. This procedure was continued for three heats, using five samples at best workable moisture and five definitely wet. After

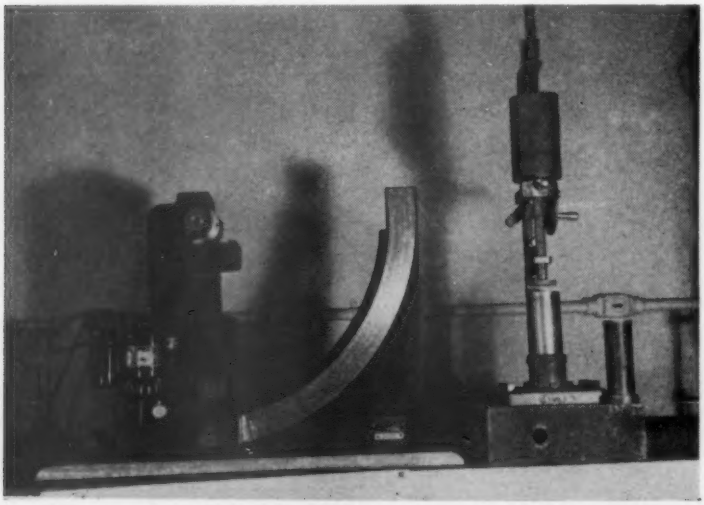

FIG. 3—RAMMING AND COMPRESSION TEST APPARATUS CONFORMING TO A. F. A. REQUIREMENTS.

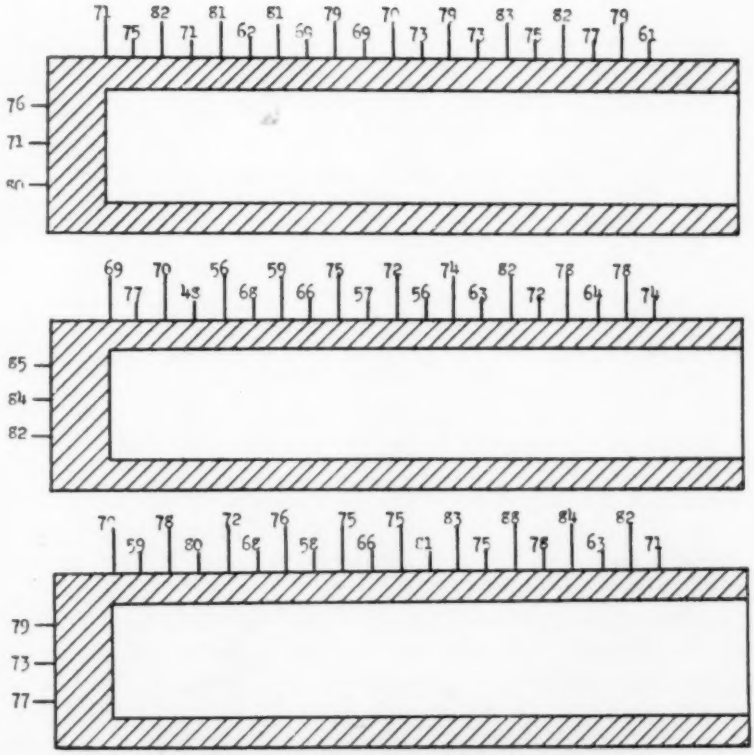

FIG. 4—GRAPHICAL REPRESENTATION OF MOLD HARDNESS TESTS.
TOP—HAND RAM—SAND ADDED IN 200 GRAM ADDITIONS.
CENTER—RAMMED WITH WEIGHTED RAMMING STICK. STICK AND WEIGHT—502 GRAMS. DROPPED 3-IN., 30 TIMES ON EACH 200 GRAMS OF SAND.
BOTTOM—RAMMED WITH WEIGHTED RAMMING STICK. STICK AND WEIGHT—502 GRAMS. DROPPED 3-IN., 50 TIMES ON EACH 200 GRAMS OF SAND. STICK ⅜x⅝x18-IN.

the third heat, the tests on the five wet samples were discontinued. Seven more heats were run with the five samples at best workable moisture, making a total of ten heats for these samples. After the tenth heat, both dry and green compression strengths of each sample of molding sand were determined.

29. Ten heats were thought to show sufficient trend in durability values. Due to unavoidable losses of sand in the testing procedure, the original 3000 grams of the sample were greatly reduced. One of the reasons for the greatest loss was the sand sticking to the castings. At the end of the tenth heat, there was barely enough sand remaining in the case of the synthetic sands to make a test mold.

Ramming Experiment

30. A check experiment was run to investigate the quality of ramming in the test molds. A weight was attached to the rammer stick so that it would strike a uniform blow when dropped from a given height. Two molds were rammed by this method, and one by hand in a split flask. When the ramming was complete, half of the flask was removed, and readings were taken with a mold hardness tester to determine the relative mold hardness. These hardness readings were compared with those obtained by hand ramming to ascertain the uniformity of ramming by the two methods (see Fig. 4). From this comparison, it was decided that the hand ramming was as uniform as the mechanical method devised to check it.

DISCUSSION OF RESULTS

Results of Fineness Tests

31. Tables 2 and 3 show the results of this test. In Table 1, showing the results obtained on the washed and dried silica sand, the distribution of the grains on the different meshes indicates that the silica sand is what is known as a well-sorted sand. A well-sorted sand has 75 per cent or more of its grains retained on any three or less consecutive screens in the sieve series.

32. Tables 2 and 3 give the results of the fineness tests performed on the naturally-bonded molding sands (Eastern and Mid-

Table 4

FINENESS TESTS OF DILUTE EASTERN NATURAL MOLDING SAND AS USED

	Per Cent Retained	
Screen Mesh	*Trial 1*	*Trial 2*
6	0.13	0.00
10	0.46	0.54
20	1.35	1.21
28	1.44	1.44
35	2.34	2.42
48	12.93	13.70
65	27.11	28.40
100	30.25	30.27
150	10.06	9.22
200	2.96	2.42
270	0.58	0.46
Pan	1.25	1.09
Total	90.86	91.17
A. F. A. Clay, per cent	8.90	8.45

Table 5

FINENESS TESTS OF DILUTE MIDWESTERN NATURAL MOLDING SAND AS USED

Screen Mesh	*Per Cent Retained* — *Trial 1*	*Trial 2*
6	0.00	0.00
10	0.21	0.29
20	0.94	0.82
28	1.18	1.10
35	2.70	2.86
48	16.35	16.94
65	32.43	32.99
100	24.94	24.22
150	6.47	6.05
200	2.16	2.01
270	0.63	0.66
Pan	2.65	2.57
Total	90.66	90.51
A. F. A. Clay, per cent	8.91	8.93

western) as received. These results show that the Eastern sand has a better grain size distribution than the Midwestern, but has less A.F.A. clay than the Midwestern. Tables 4 and 5 give the results of the tests run on the naturally-bonded molding sands diluted with silica sand as they were used in the tests. A comparison of Tables 4 and 5 shows that adding silica sand to the naturally-bonded molding sands had the effect of equalizing both the clay percentage and the grain distribution.

Clay Additions

33. Table 6 gives the additions of each of the various type clays to the synthetic sand samples during the ten heat repeated-pour test to maintain the required 6 lb. per sq. in. green compression strength at best workable moisture. The table presents two possible ways of considering clay additions as a measurement of durability. The first method is to consider the average amount of clay bond added per heat during the ten heats. However, some economic phases of this problem might demand the consideration of the amount of original clay bond present in the molding sand before the first heat. Therefore, a total figure is shown, giving the sum of the clay bond present in the molding sands before the first heat plus the clay bond additions during the ten heats. In the tests on the naturally-bonded molding sands, the additions were made in the form of grams added of naturally-bonded molding sand as

Table 6

CLAY ADDITIONS MADE TO MAINTAIN REQUIRED GREEN COMPRESSION STRENGTH IN TEN HEATS. SAMPLES AT BEST WORKABLE MOISTURE (SYNTHETIC SANDS)

	Illite	*Montmorillonite*	*Kaolinite*
Clay addition before 1st heat, grams	191	120	259
Clay additions in 10 heats, grams	181	132	122
Average additions per heat, grams	18.1	13.2	12.2
Total clay used, grams	372	252	381

Table 7

NEW SAND ADDITIONS MADE TO MAINTAIN REQUIRED GREEN COMPRESSION STRENGTH IN TEN HEATS. SAMPLES AT BEST WORKABLE MOISTURE (NATURAL MOLDING SANDS)

	Eastern Natural Sand	*Midwestern Natural Sand*
Silica sand necessary, grams	1170	1765
New sand necessary before 1st heat, grams	1830	1235
New sand additions in 10 heats, grams	5030	3725
Total new sand used, grams	6860	4960

Table 8

CLAY ADDITIONS MADE TO MAINTAIN REQUIRED GREEN COMPRESSION STRENGTH IN TEN HEATS. SAMPLES AT BEST WORKABLE MOISTURE (NATURAL MOLDING SANDS)*

	Eastern Natural Molding Sand	*Midwestern Molding Sand*
Clay addition before 1st heat, grams	240	220
Clay additions in 10 heats, grams	660	648
Average additions per heat, grams	66	64.8
Total clay used, grams	900	868

received. These additions are shown in Table 7. To bring these additions to the clay addition basis used in Table 6 for the synthetic sands, each amount was multiplied by the percentage of clay present in the type of naturally-bonded molding sand. For example, Eastern naturally-bonded molding sand required 5030 grams of new sand during the ten pourings to maintain the required green strength. Thus, 5030 x 0.1312 equals 660 grams of clay bond added (13.12 per cent clay in the Eastern natural molding sand). These results are shown in Table 8.

* The amount of clay calculated by multiplying grams of sand added by per cent clay present in the molding sand.

Table 9

DRY COMPRESSION STRENGTH OF SANDS AT BEST WORKABLE MOISTURE BEFORE THE FIRST HEAT AND AFTER TENTH HEAT

Samples	Dry Compression Strength lb. per sq. in. Before First Heat	After Tenth Heat	Per Cent Decrease
Illite	14.3	6.2	56.7
Montmorillonite	48.1	26.9	44.1
Kaolinite	24.7	5.7	76.9
Eastern Natural	19.5	9.9	49.3
Midwestern Natural	47.1	20.4	56.7

Table 10

CLAY ADDITIONS BY HEATS—SAMPLES AT BEST WORKABLE MOISTURE (GRAMS)

Samples	No. of Heats Before	1	2	3	4	5	6	7	8	9	10
Illite	0	25	10	10	12	18	15	15	20	30	26
Montmorillonite	0	20	9	9	10	20	10	10	10	17	17
Kaolinite	0	10	0	10	0	30	10	9	17	18	18
Eastern Natural	3.9	25.2	92.2	39.4	55.8	88.5	65.7	78.9	65.7	78.9	65.7
Midwestern Natural	2.6	138.1	51.9	26.0	34.6	73.5	69.2	65.0	64.9	62.3	65.0

Table 11

PER CENT MOISTURE BY HEATS WITH SAMPLES AT BEST WORKABLE MOISTURE

Samples	No. of Heats Before	1	2	3	4	5	6	7	8	9	10
Illite	2.2	2.4	2.2	2.4	2.2	2.3	2.1	2.4	2.4	2.4	2.4
Montmorillonite	1.8	1.8	1.8	2.2	2.0	2.0	1.9	2.1	2.1	1.9	2.1
Kaolinite	2.9	2.6	2.8	3.1	2.9	3.1	3.0	3.1	3.0	3.0	2.9
Eastern Natural	4.6	3.0	4.4	4.7	4.4	4.5	4.7	4.6	4.6	4.5	4.5
Midwestern Natural	4.1	4.0	4.0	4.3	4.2	4.1	4.1	4.2	4.0	4.2	4.1

Dry Compression Strength Results

34. Results of the dry compression tests before the first and after the tenth heat, are given in Table 9. An interesting condition is shown in regard to the percentage decrease in dry compression strength from before the first until after the tenth heat. The fact that this decrease in dry compression strength took place while the green compression strength was being constant is very significant. It should be pointed out, however, that the baked specimens were not cooled in a desiccator. Some investigators feel that if this is not done, the results obtained by the dry compression strength test may not be accurate. Nevertheless, the results are included in this report for what they may be worth.

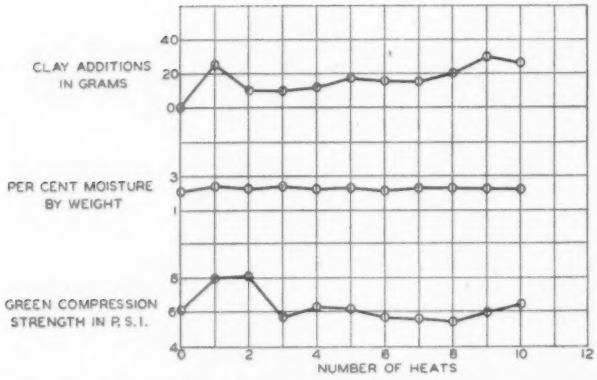

FIG. 5—CHART SHOWING TYPICAL VARIATIONS FROM STANDARD CONDITIONS AND CLAY ADDITIONS USED IN THE INVESTIGATION. THESE DATA ARE OF THE ILLITE-BONDED SANDS.

Variation in Properties Desired

35. Tabulation of the clay additions by heats for the samples at best workable moisture content is given in Table 10. As the heats progressed, it was possible to regulate the clay additions in such a manner that the variation from the desired 6 lb. per sq. in. green compression strength was less than at the start of the test, due to experience in making the additions. This can be seen more clearly in the graphical representation in Fig 5, which is typical of the variations throughout the investigation.

36. Results of the moisture tests, with the samples at best workable moisture content, are given in Table 11. It already has been explained how the choice of the amount of moisture was made by the "feel" method. It also was explained, in the section procedure, that the method of tempering the sand was long and presented difficulties in obtaining the exact moisture desired. To show a typical deviation within a series of tests, and to be able to judge its effect upon results, all three curves of moisture, clay additions, and green compression strength were plotted together in Fig. 5. For example, Fig. 5 (Illite bonded at best working moisture) shows clay additions of 25 grams, moisture 2.4 per cent, green compression strength, 7.02 lb. per sq. in.

Explanation of Variations in Moisture and Strength

37. Results of the green compression strength tests with samples at best workable moisture content, are given in Table 12. Considerable variation from the desired 6 lb. per sq. in. green com-

pression strength is shown. However, a number of factors tend to explain this variation. The clay additions were made by guess and can be expected to be inexact in the first few heats.

38. There is a difference in the green strength at the time the sand is in the mixing machine and when it is tested after tempering in glass bottles 24 hours later. This difference in green strength occurred, for example, in the illite bonded sand at temper after the first heat. When the sample was mixed with 62 cc. of water for the required 7 min., the tests for per cent moisture and green compression strength were performed. The results of these tests were 2.2 per cent moisture and 4.9 lb. per sq. in. green compression strength. Ten grams of clay and 10 cc. of water were added, and the molding sand was mixed for 5 min. The tests showed 2.4 per cent moisture and 5.4 lb. per sq. in. green compression strength. A second addition of 15 grams of clay and 10 cc. of water was made. After mixing 5 min., the tests were repeated. The results were 2.5 per cent moisture and 6.2 lb. per sq. in. green compression strength.

39. After being sealed in a glass bottle for 24 hours, the sample was again tested. As recorded in Tables 11 and 12, these results were 2.4 per cent moisture and 7.02 lb. per sq. in. green compression strength. Also, if the moisture were incorrect, it was necessary to retemper the sand. In retempering the sand, additional mixing

Table 12

GREEN COMPRESSION STRENGTH BY HEATS WITH SAMPLES AT BEST WORKABLE MOISTURE

Samples	*Green Compression Strength by Heats, lb. per sq. in.*										
	Before	*1*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Illite	6.03	7.02	7.10	5.67	6.25	6.15	5.60	5.55	5.32	5.95	6.40
Montmorillonite	6.60	6.95	7.50	5.27	5.87	6.37	6.32	5.70	6.00	5.77	5.62
Kaolinite	5.70	6.92	7.77	5.90	5.50	7.15	6.37	5.10	5.97	5.27	6.00
Eastern Natural	6.05	6.92	8.57	5.25	5.50	5.90	5.40	5.47	5.82	6.02	5.67
Midwestern Natural	6.70	7.85	9.95	5.45	5.57	5.95	6.72	5.80	6.82	5.67	5.82

Table 13

CLAY ADDITIONS BY HEATS—WET SAMPLES

Samples	*Before*	*Additions, grams*			*Total Additions, grams*	*Total Clay Used, grams*
	1	*1*	*2*	*3*		
Illite	0	20	15	10	45.0	236.0
Montmorillonite	0	10	10	15	45.0	265.0
Kaolinite	0	10	0	5	15.0	264.0
Eastern Natural	3.9	45.9	65.6	78.8	190.3	430.3
Midwestern Natural	12.6	104.0	43.2	51.8	199.0	419.0

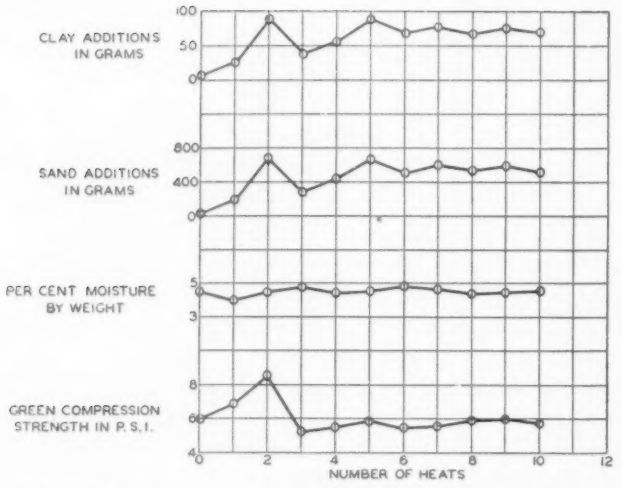

FIG. 6—SAME AS IN FIG. 5 BUT FOR EASTERN NATURALLY-BONDED MOLDING SAND. CLAY ADDITIONS ARE INDICATED ON THE BASIS OF BOTH CLAY SUBSTANCE ADDITIONS AND TOTAL SAND ADDITIONS.

of the sands in the mixing machine tended to increase the green compression strength.

40. The results of the clay additions tabulation, the moisture tests, the green compression strength tests, and the dry compression strength tests are shown in Tables 13, 14, 15 and 16. Due to the inability to judge the clay additions correctly on the early heats, the results are not entirely conclusive. However, it is thought that the results do indicate that there is no great difference between the durability of the wet and best workable moisture samples. Perhaps this is best shown by comparing the typical graphs of the clay additions, the per cent moisture, and the green compression strength for the wet samples as shown in Fig. 6 with those for the best workable moisture samples in Fig. 5.

Uniformity of Ramming Test Molds

41. Figure 4 shows the results of the test to check the uniformity of the hand ramming method of the test molds. It was believed that placing the mold hardness readings on the cross-sectional view of the mold was the best way to show the comparison of the hand method and the weighted stick method of ramming. If the mold hardness test can be taken as a standard of comparison of the uniformity of the ram, the results of the tests in

Fig. 4 show that the method of hand ramming was more uniform than the other methods used.

SUMMARY AND CONCLUSIONS

Summary of Results

42. Considering only the clay additions made during the ten heats for the best workable moisture samples, a comparison of the durability of the various mixtures by this method group themselves as follows:

a. Kaolinite-bonded sand is first with additions of 122 grams of clay.

Table 14

MOISTURE TESTS BY HEATS—WET SAMPLES

Samples	*Moisture Per Cent*			
	Before			
	1	*1*	*2*	*3*
Illite	3.2	3.0	2.9	3.2
Montmorillonite	2.8	2.2	2.7	3.0
Kaolinite	3.8	3.6	3.4	3.9
Eastern Natural	5.8	5.3	5.7	5.7
Midwestern Natural	4.3	4.4	5.2	5.0

Table 15

GREEN COMPRESSION STRENGTH TESTS BY HEATS—WET SAMPLES

Samples	*Green Compression Strength in lb. per sq. in. No. of Heats*			
	Before			
	1	*1*	*2*	*3*
Illite	3.7	4.2	5.0	4.1
Montmorillonite	4.6	4.6	5.0	4.0
Kaolinite	3.0	3.3	4.5	3.1
Eastern Natural	4.3	4.0	3.8	4.2
Midwestern Natural	4.8	5.6	4.7	4.9

Table 16

DRY COMPRESSION STRENGTH TESTS OF THE WET SPECIMENS BEFORE AND AFTER FIRST HEAT

Specimen	*Dry Compression Strength, lb. per sq. in.*		*Per Cent of Decrease*
	Before 1st Heat	*After 3rd Heat*	
Illite	32.6	22.3	31.6
Montmorillonite	75.12	51.2	31.9
Kaolinite	35.3	21.1	41.1
Eastern Natural	22.3	19.5	12.5
Midwestern Natural	63.1	41.8	33.7

b. Montmorillonite-bonded sand is second with additions of 132 grams of clay.
c. Illite-bonded sand is third with additions of 181 grams.
d. Midwestern natural sand is fourth with additions of 648 grams of clay.
e. Eastern natural sand is fifth with additions of 660 grams of clay.

43. Considering the total clay used, both before and during the ten heats for the best workable moisture samples, a comparison of the durability of the various mixtures by this method group themselves as follows:

a. Montmorillonite-bonded sand is first with 252 grams of clay added.
b. Illite-bonded sand is second with 372 grams of clay added.
c. Kaolinite-bonded sand is third with 381 grams of clay added.
d. Midwestern natural sand is fourth with 868 grams of clay added.
e. Eastern natural sand is fifth with 900 grams of clay added.

44. Although the natural molding sands have been placed on the "clay added" basis by multiplying the grams of sand added by the percentage of clay, it is doubtful whether the natural sands should be compared with the synthetic sands with regard to clay added. The reason for this is that the A. F. A. method of determining the percentage of clay substance in a sand or sand mixture may include a definite amount of silt or non-bonding material*.

Conclusions

45. From the results of this investigation, the following conclusions may be drawn:

1. As previously stated, the five sands used in these series of tests include three synthetic sand mixtures and two naturally-bonded sands. Each of the synthetic sands was bonded with one of the three recognized classes of clays, namely, kaolinite, montmorillonite, and illite.

2. The results of tests on the sand samples bonded with these

* Grim, Ralph E., and Schubert, Carl E., *"Mineral Composition and Texture of the Clay Substance of Natural Molding Sands,"* TRANSACTIONS, American Foundrymen's Association, vol. 47, pp. 935-953, 1939.
Grim, Ralph E., *"Elements of the Petrographic Study of Bonding Clays and of the Clay Substance of Molding Sands,"* TRANSACTIONS, American Foundrymen's Association, vol. 47, pp. 895-908, 1939.

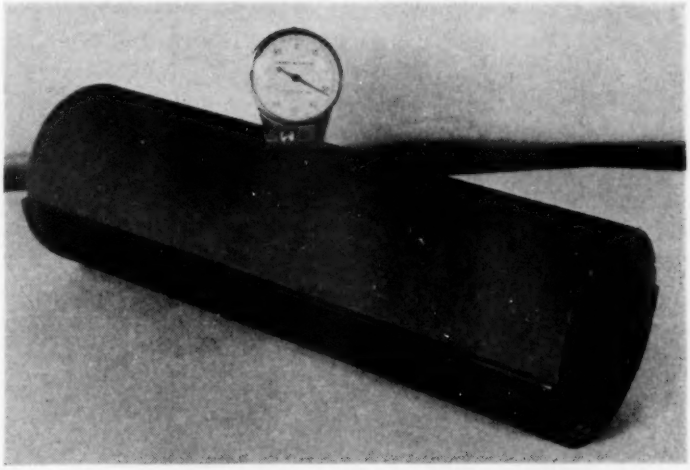

FIG. 7—METHOD OF TAKING MOLD HARDNESS READINGS.

various type clays may be used as a guide to the durability of synthetic sand mixtures in commercial foundries when such sands are used under conditions similar to those existing in the series of tests.

3. The durability values obtained on the naturally-bonded sands show that, under the conditions of these tests, the amount of natural clay bond needed to produce the required 6 lb. per sq. in. green compression strength throughout the test series was at least twice as much as that required for synthetic sands to maintain the same strength.

4. Based on additions of new sand, it might be possible that none of the original naturally-bonded sand sample existed in either of the two naturally-bonded sands tested after the final test. In the case of the Eastern naturally-bonded sand, 6860 grams of new sand were added in the ten heats, and in the case of the Midwestern naturally-bonded sand, 4960 grams were added. In both cases, the original sample weight was 3000 grams.

5. The above results seem to indicate that synthetic sands have a greater durability than do natural sands.

6. Whether or not the data obtained on the two natural sands tested is applicable to all types of natural sands is doubtful, as the results obtained with other naturally-bonded sands would depend upon the mineral constituents of the natural clay bond.

7. The data obtained in this investigation has produced durability values on specific sand mixtures which can serve as a basis for correlating the results obtained in future work in connection with the invention of a rapid and reliable laboratory method for determining the durability of foundry sands.

8. Data accumulated in a series of tests with samples of each type sand tempered to contain 1 per cent more moisture than the best workable moisture content appear to indicate that tempering sands to the wet side has little effect on the durability.

9. Further investigation may be indicated with regard to the possibility of connecting the determination of durability values with dry compression strength instead of green compression strength.

ACKNOWLEDGMENTS

46. Acknowledgment is made to Assistant Professor Carl E. Schubert for supervision and assistance in performing and writing the tests, to Professors Carl H. Casberg and Oscar A. Leutwiler for aid in writing the thesis, to the Subcommittee on Durability, American Foundrymen's Association Foundry Sand Research Committee, for suggesting the subject of the investigation and to members of the Association for supplying the materials.

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DISCUSSION

Presiding: L. B. KNIGHT, JR., National Engineering Co., Chicago, Ill.

Co-Chairman: F. L. WEAVER, Great Lakes Foundry Sand Co., Detroit, Mich.

H. RIES (*written discussion*)[1]: The writer has read with interest the results of the author's investigation of the durability of various type bonding clays under the standard conditions as set forth for the investigation. While the author reaches some interesting conclusions, the writer feels that his charts might be open to some criticism. The charts in the paper show the accuracy with which the additions of the various type clays were made to maintain the required 6 lb. per sq. in. green strength and also the author's ability to hold the green strength to the standard mentioned. However, the writer feels that other than this, the charts give no particular evidence as to the total amount of any of the clays used in the experiment. He believes that a cumulative curve based on the data as set forth in the paper might be of some interest and, therefore, submits the chart shown in Fig. 8.

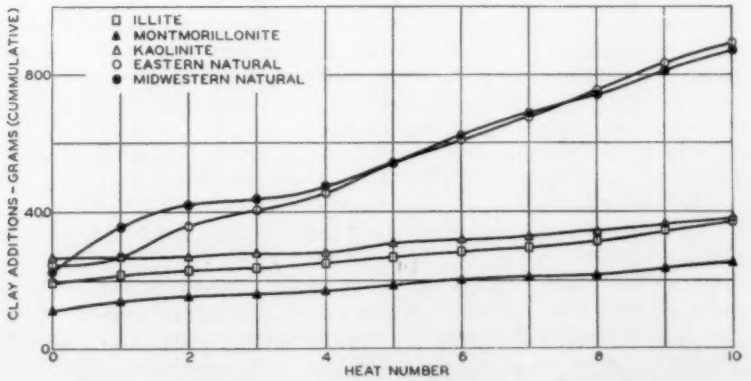

FIG. 8—CHART SHOWING THE AMOUNTS OF CLAY USED THROUGHOUT THE TESTS IN A CUMULATIVE MANNER. IT SHOULD BE REMEMBERED THAT THE CLAY CONTENT OF NATURALLY-BONDED SANDS, AS DETERMINED BY THE A.F.A. CLAY SEPARATION TEST, CONTAINS SOME SILT.

[1] Technical Director, A.F.A. Foundry Sand Research Committee, Ithaca, N. Y.

It will be noted that on this basis, there is not a great deal of difference in the total amount of clay of either the illite or kaolinite types used in the test. On the other hand, the montmorillonite type required the least clay to produce the necessary 6 lb. per sq. in. green strength at the beginning of the test and also the least total amount of the three clays used throughout the test. However, it will be noted that the average slope of the curves for the three clays is about equal.

The two curves for the eastern and midwestern naturally-bonded sand additions are based on the clay content of the sand. These two curves are much steeper than those shown for any of the three general types of clays used but must not be interpreted as being evidence that more natural clay contained in naturally-bonded sands is necessary to maintain a given green compression strength.

The reason is apparent because the clay content of the naturally-bonded sands, upon which these curves are based, was obtained by the A.F.A. clay separation method. In this method, it is admitted that a certain percentage of fine silt remains in suspension and is siphoned off along with the true clay substance. As fine silt has little or no bonding power, it would exert a great effect on the results obtained in any experiment in which the amount of clay obtained from naturally-bonded sands was used as a criterion of the bonding capacity of the clay of such sands.

It would have been interesting had the author been able to make a petrographic analysis of the clay material obtained by the A.F.A. standard clay separation method to determine which of the three general types of clays were present in each of the naturally-bonded sands used in the experiments.

Following this, an attempt might have been made to separate the true clay from the naturally-bonded sands, and then mix it with the sand used in the other mixtures.

The paper also contains some interesting figures on the dry strength of the different mixtures. Too much weight should not be attached to these, as they were allowed to cool in the air before testing. Had they been cooled in a desiccator, the results would probably have been quite different.

CHAIRMAN KNIGHT: What check was made on the amount of the fines accumulation in the sand to determine the effect of this accumulation on the dry strength? Is it true that the accumulation of fines would tend to show a higher green strength and yet actually the dry strength would be lower?

MR. COVAN: I did not make a check of the fineness distribution after the heats were run. I think that it should be done and that it would give information that would bear out your statement about green and dry strength.

H. W. DIETERT[2]: In place of stressing durability in grams of clay added, perhaps it would be more practical to stress the cost of the material added, taking, for example, Chicago, Detroit and Newark as basing points. In that way, we would have a more practical figure.

[2] Harry W. Dietert Co., Detroit, Mich.

MR. COVAN: I think your suggestion might have value in regard to applying the durability test to a foundryman's use. The values of this particular paper are set up in an effort to provide a basis of determining whether or not a proposed method is reliable or not. The whole point in doing this test work is to set a basis. I think we are all agreed that the repeated-pour test method is the best we have at present. Therefore, we will use the data obtained in this investigation as a basis in checking whether or not any proposed method is successful.

MR. DIETERT: The author's tests show, for example, that bentonite is 132 grams; kaolinite, 122 grams. Somebody might think that the cost for 132 grams of bentonite would come awfully close to kaolinite, but the cost is high for 132 grams of bentonite as compared to 122 grams of clay. If we are going to use both of these figures as indices in durability, I believe we would have to consider the cost.

CHAIRMAN KNIGHT: I believe that your comment is correct so far as the practical application is concerned, but I do not think that was the purpose of the paper. The purpose of the paper was to try to establish a practical series of tests to determine how much material must be added to maintain a required strength rather than how much it costs to maintain that strength.

RUSSELL MANLEY[3]: I believe that different kinds of castings and different kinds of sand give a different result. Two examples might be pouring a car wheel and pouring ornamental curtain hangers. When a car wheel mold is shaken out, the sand is red. The clay is getting tremendously more severe treatment than the clay in a light casting shop. The durability factor is directly related to the kind of work the sand is taking care of.

We also find that the permeability of the sand, plus the weight of the casting, affects the depth to which the heat penetrates. The depth to which that heat penetrates directly affects the durability of the sand for it is the factor which determines how far back the clay is dehydrated.

MR. COVAN: The main thing about that suggestion is the fact that we are trying to set up an average condition and confine it specifically to a medium class of sands used, approximately 6 lb. per sq. in. green compression strength. After we determine a successful test method, then there is a possibility of investigating these various outside effects and possibly suggesting modified forms of the test to cover varying conditions.

Our sand-to-metal ratio in these tests was one weight of sand to two weights of iron which was thought to be severe enough in this particular case to make our results readily noticeable.

MR. MANLEY: An average determination is a good thing, but is it what we want? After we get the results, do they mean anything?

We have just started some work on durability and it begins to look as if the temperature to which we heat the mold surface should be directly correlated to the type of sand we are using. When using a fine sand, the mold surface should not be heated to anywhere near the temperature

[3] Manley Sand Co., Rockton, Ill.

it is when using a very heavy sand.

MR. COVAN: The Subcommittee on Durability of the A.F.A. Foundry Sand Research Committee has been following the durability problem with the idea of trying a number of different test methods. They have suggested investigating the temperature to which the surface of the mold is subjected in a panel form, etc. But what are the results to be compared with if there are no values to start with?

MR. MANLEY: Would it not be better if we started by measuring mold temperatures, starting with the finest castings and working up to the largest castings, getting the temperature back from the surface of the mold as close as we can put a thermocouple and get a satisfactory result and finding out through that data what heat we are getting on all these different weights of casting, or, shall we say, in the different kinds of sand? From there we can work into our durability.

MEMBER: I am in hearty accord with Mr. CoVan. I believe that his entire work has been as a guide to the shop men. We have been given information as to what one material will do in regard to another, and it is up to us to decide which material is going to be the most practical and most economical under our own conditions.

N. J. DUNBECK[1]: Dr. Ries' comments suggested that our interpretation of the facts presented depends upon how we rearrange them and look at them. That is true and, possibly in looking at the durability test. we should consider the fact that one foundryman might be looking for something very different than another.

In this series of tests, I understand the author started with a comparatively large amount of sand, additional material being added on each remix. Therefore, on the first few heats, he had a fairly substantial amount of new material going in, which might be similar to the case of a man using the sand only a few times. At the end of those tests, he might have been getting closer to the typical gray iron system where the sand is used repeatedly.

It is a case of rearranging the results and looking at them from each particular angle. One man might say he is interested only in the first four heats. I noticed one of the illite curves seemed to pitch a little sharper than the other. A man looking at the first four heats would find he had added 57 grams of illite as compared with 48 grams of montmorillonite. A man looking at the last four would see he had added 91 grams of illite as compared to 54 grams of montmorillonite.

CHAIRMAN KNIGHT: From a practical standpoint, each foundryman has to interpolate these results to his own conditions of operation. There are many other variables that will enter into it. The type of equipment he has, and the condition of his sand will definitely affect any results he might get. In experimenting with fines control, a good many conditions are upset on which all these durability tests have been based for years and years. A mechanized foundry today cannot be operated with any high degree of success or economy without controlling the sand.

There is a lot in this subject of durability and it has a very definite

[1] Eastern Clay Products, Inc., Eifort, Ohio.

effect on the sand, not only on the cost of the materials being used but on the cost of cleaning and finishing castings.

E. C. SAWYER[5]: I agree with Mr. Manley that the average foundryman should not try to interpret these results in terms of his castings unless his castings are somewhat comparable. If it is a foundry that has very heavy castings and very open sand, or, to take the other extreme, a very light foundry with a tighter sand, the foundryman could not take these average tests to mean anything to his foundry except as a means for him to determine tests from which he could get his results.

MR. MANLEY: That is right. I think we ought to set up a classification of sands and determine what these sands are going to be used for. There is a limit on that, of course, but moving up in permeability brings into consideration a different range of castings that are put into these sands. I think we should take that factor and determine it.

For instance, we are doing some work on durability with a gas-fired furnace. The sand is 2¼-in. deep, the mold face is 3-in. high and 4-in. in diameter, open at each end. The mold face can be heated to 2500°F. in 5 minutes, and we know that with a sand of approximately 10 permeability, and the mold face heated to 2500°F., we cannot pour any kind of gray iron because, in sand of 10 permeability, no one pours a heavy enough casting to get the mold face up anywhere near that high a temperature. On that kind of sand, it is necessary to adjust the temperature of the mold face to the type of metal poured into it.

CO-CHAIRMAN WEAVER: I am in accord with Mr. Manley regarding the variable that exists due to weight or cross-section of a casting. All this leads to my personal opinion about durability. Why not eliminate all these factors of cross-section, weight of casting, type of sand, etc., by putting more thought and effort on some means of determining the durability of the clay or bond involved rather than sticking to this idea that it must be done by the recast method?

M. E. GANTZ[6]: It seems to me that if the sand and all conditions of the test are kept the same, the durability of the clays involved very definitely will be determined by the method described by Mr. CoVan. As long as the same sand is used throughout the test and as long as all other factors of the test are kept the same, the durability of the sand being tested is dependent upon the clay, and, hence, the test will demonstrate the durability of the clay.

CO-CHAIRMAN WEAVER: That does not take care of the man who wants to know how durable a material is for his work under his conditions at certain temperatures, etc., or the cost per unit weight of castings.

MR. GANTZ: That may be true, but it is practically impossible to set up a test that will satisfy the conditions of all the foundries existent and answer each man's separate problem.

CO-CHAIRMAN WEAVER: I do not agree with you. If we determine once and for all the relative durability of one specific factor, the clay, the bond, and then, by simple deduction and test, everything being con-

[5] Ayers Mineral Co., Zanesville, Ohio.
[6] American Magnesium Corp., Cleveland, Ohio.

sidered, determine in one particular case which of the materials is the best, we have the answer to the problem.

MR. GANTZ: Can the durability of any specific clay be determined from the test described?

CO-CHAIRMAN WEAVER: Yes, provided the same long and tedious procedure is performed, but the results will only hold true for identical conditions which may not prevail at one foundry in a thousand.

MR. GANTZ: It seems to me that any general test still will not give the information desired.

CO-CHAIRMAN WEAVER: On the contrary, if we agree that the durability of a sand is related to the durability of the bond and we have the relative durability of the bond, that factor becomes a constant for further calculations in a study of the other variables.

MR. GANTZ: For how many heats?

CO-CHAIRMAN WEAVER: That is arbitrary.

MR. GANTZ: Arbitrary from foundry to foundry. The durability will vary according to the grain size of the sand.

CO-CHAIRMAN WEAVER: No, I do not say that. I say the durability of a sand varies with the durability of the bonding agent, particularly. The grain size is a variable of secondary consideration.

MR. GANTZ: I do not see why we cannot derive that from this test as well as from any test which might be devised.

CO-CHAIRMAN WEAVER: I don't say that you cannot, but the present re-cast method seems too long drawn out and not to the point.

MEMBER: When an attempt is made to draw conclusions as to durability of a clay through any test on that clay without regard for the variables of use, it means a lifetime job. We have spent a lot of time and money on it so far.

CO-CHAIRMAN WEAVER: The only point I am making is that we seem to have a lifetime job as it is in trying to satisfy every individual condition. If we start right and decide first of all the relative durability of the bonding agents, the other factors may prove less difficult.

MEMBER: Almost every material that enters into the foundry must be considered in certain groups. If we cannot take one durability test as far as Mr. CoVan has and say that it applies to all groups, can we take several different groups and calculate, by some practical use test, something that introduces the variables which the foundryman will find in use? I do not think we can get anything without it.

CO-CHAIRMAN WEAVER: Agreed. I hope that I have not been misunderstood. I am not detracting in the least from Mr. CoVan's work. He pointed out himself that the Subcommittee on Durability decided that the re-cast test, at the present time, was the proper test to make. I still insist that, if we put enough effort on the subject, we will be able to solve the fundamental problem of the durability of the bonding agent first and then start on a program of the influence of sand fineness and other variables without the laborious re-cast work.

DR. RIES: I have been listening to these varying opinions with interest. I do not think that we should consider the Durability Subcommittee work

as finished. It has just started. Personally, I would like to see this same set of experiments run with a coarser sand and see if we can get the same relative results. Or we might also try running it and using a larger casting.

I do not think the subcommittee said this is the thing to do. I think they said it is the best thing to try first.

CO-CHAIRMAN WEAVER: I agree with you. All I am trying to do is to get a little more interest in some other means of testing durability.

DR. RIES: Do you prefer to try the clay alone and see how long some of it will last?

CO-CHAIRMAN WEAVER: I still have confidence that some means will be found for determining the relative strength or other physical properties of the clay after a progressive heating of the clay itself, subjecting it to dehydration and then using it, after each successive temperature treatment in the standard A.F.A. strength test, or even in a casting test, to determine the properties in that regard rather than just the breakdown that occurs in the present re-cast durability method.

MR. COVAN: That is exactly the use to which we want to put the values that we have obtained. A lot of people have ideas as to how to tackle a problem but who is going to say which idea is good? I think we should take the results on these identical materials, compare them to the values we got and see how they stack up.

MR. DIETERT: We could make a little progress if we would test our sands under different temperature ranges. Those for steel would, perhaps, be heated to 2700°F. and tested; for heavy gray iron, 2600°F.; light gray iron, 2400°F.; and non-ferrous, down to as low as 2000°F. or into the 1000°F. range. It would be a tremendous amount of work but it might satisfy the two schools of thought.

Gating Malleable and ArmaSteel Castings†

By F. E. Reeves*, Saginaw, Mich.

Abstract

Since the beginning of the malleable foundry industry, problems of gating castings and causes and methods of eliminating scrap in malleable castings, have existed. Due to these facts, the author has described different methods used by his foundry in the gating of malleable iron castings. Every casting is practically a new problem in itself, as they all are laid out differently. The ability to arrange gates and make pattern layouts comes only from experience and practical knowledge of the foundry.

There are many causes of defects in castings; some are shrinks, cold shuts, misruns, scabs, chill kicks, hot cracks, and mottled iron. This paper covers the changes that have been made in the author's foundry to eliminate and reduce the total per cent of scrap on their castings.

Introduction

1. This paper is on the methods of gating malleable and "ArmaSteel" castings, which are entirely on production in our foundry. The majority of our patterns are laid out in a composite form of grouping the large and small castings in one mold. Machine line and double match molding are at present the greatest part of our pattern equipment.

2. All our drop plate equipment in machine molding is standardized to 20 x 20 and 20 x 23-in. in length and width, with the depth of the cope and drag varying with the type of job. Double match copes and drags are made on the same machines using drop plate pattern equipment with a standard flask size of 16½-in. x 18½-in. x 5-in.

3. Our patterns are mounted on drop plate equipment on 16-

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in. cylinder molding machines. All our jobs have individual squeeze blocks made of hard maple. The taper of the blocks varies from 2° to 10° depending upon the type of the pattern. The blocks will vary in length according to the mold being made. Molds squeezed too hard over certain parts of the pattern will cause scabs and blows.

4. Pattern layouts, gating arrangements, and fillets are the hardest to determine because, to date, there is no set or fast rule as to the gating of malleable iron castings. Sometimes one will have to use exactly the opposite method than had been employed on previous jobs.

5. Dendritic structure in castings is one of the hazards of the foundry. Using chills wherever possible, and holding carbon content around 2.70 per cent, helps to prevent this structure. Changing the types of chills as to size and contours, or arranging the chills in different sections of the castings, are items that have to be taken into consideration. Chill kicks and blow are sometimes caused by the condition and arrangement of the chills.

6. The foundry has a synthetic sand system, where the sand is mixed in a continuous muller. Each sand unit has approximately a 165 ton capacity. The amount of sand used per hour is 100 to 120 tons. The sand temperature at the molder's hopper averages 135°F. during the winter months. Moisture content varies from 4.5 to 5.0 per cent due to the condition of the weather, the types of jobs, etc. Permeability varies from 36 to 42, clay content 12 per cent, sea coal 5.5 per cent, and the core sand fineness varies from 65 to 70.

7. Today, due to aluminum shortage, patterns in our plant are being made from ArmaSteel with hardened chill and core seats. Some of the patterns have run steadily for over one year without being repaired. The average molds produced from these patterns average 1500 per 16 hrs., 5 to 6 days per week.

SLAG

8. Slag is usually caused by impurities or agitation of iron in molds. Any foreign substance in the iron such as dirt from molding sand causes slag to form. To prevent the formation of slag, it is essential that all runners and molds be kept free from dirt, fins, etc. Slag is, indeed, one of the trouble makers in the production of good, sound castings and, as yet, there is no positive prevention for it.

9. Occasionally slag will enter the mold with the iron, and will also form in the casting during the process of pouring. The disturbing action of the iron causes the impurities to become localized and oxidized, and no longer an intimate part of the iron. The slag formed usually floats to the surface near the gate.

10. The greater the disturbance of the iron, the more slag will be formed. For example, take any ladle full of iron and skim it free of slag. A clean iron rod placed in the iron will form slag immediately due to the boiling and disturbing action caused by the rod.

11. Pouring iron in pigs will cause slag to form immediately at the point where the iron enters the mold. Slag will form in a heavy casting which is all located in the drag half of the mold, due to the distributing action of the iron which is similar to the reaction developed when pouring iron into a pig. Slag will usually accumulate at the flat surface in the cope at the gate.

12. Several methods are used to eliminate or distribute slag in the molds. Some are as follows: Placing a skim core at the base of sprue; skim core in cope sprue cup; skim core used on offset sprue; skim core placed in cope at mouth of sprue; and skim core at base of sprue; and in castings with tall perpendicular walls gate cores are usually used. A small slab core set in the basin has worked out satisfactorily on several patterns.

13. In one case, differential carriers were showing approximately 15 per cent slagged castings. In an experiment of gating, runners were built larger, chokes and so-called slag catchers were used, but slag still prevailed. Castings and runners were left together and then sand blasted. The carriers showed slag at the bottom gate and the runners also accumulated slag. The runners were gradually reduced to $\frac{5}{8}$-in. and the choke in the runner down to $\frac{3}{8}$-in. The scrap due to slag was entirely eliminated. Changing the gating arrangement of the carrier so the iron would feed in from the drag decreased the disturbance of the iron and the formation of the slag. We think the above statements will prove that most slag is formed in the mold.

SHRINK AND SHRINK CRACKS

14. Shrinkage is usually encountered in every malleable iron casting. The correct design of the pattern and the exact location of the shrink bobs, are factors to be taken into consideration when

trying to eliminate this shrinkage. Locating the bobs requires a great deal of experience and practical knowledge. Sometimes shrinks will result from either adding or removing metal.

15. Shrinkage will usually occur in a casting where a heavy section joins a light section. In the process of cooling, the heavy section will feed the light section and the heavy section will begin to shrink unless live iron is brought in by aid of a shrink bob. In some types of castings it is difficult and sometimes impossible to gate in the section shrinking. In these cases chills are often used. Chills will cause scrap, such as chill blows, and will tend to drive the shrink to some designated point in the casting. Several different designs of chills may have to be used before one is found to cool the section properly, to give a shrinking rate the same as the rest of the casting.

16. Hot or cold iron will cause a shrink. The design of the pattern plays an important part in eliminating shrinkage. There are several rules that must be followed as to gates, size, position, and location of the bobs or feeders. The bobs should be as close to the casting as possible and feasible, and the gates as large as possible, with the breaking point in exact place and parallel to the casting at that point to avoid a break in the castings. The basins also must be tapered back to prevent sand from washing into the castings. Gates of the casting must remain hot or in a liquid state until the casting is entirely fed, therefore, basins should be made one-half the height of the bob. The bob should extend to the same height or above the height of the casting in order to get best results. As a rule live bobs are used wherever possible, but "blind" or "dead" bobs have been used and produced good results.

17. In some instances, blind or dead shrink bobs give better results than live ones. Shrinks in a hanger casting were removed by making shrink bob dead, as shown in Fig. 1.

HOT CRACKS

18. Hot cracks are a menace to the malleable iron industry, and, as is well known, cause considerable scrap. The hot cracks are due to the linear shrinkage of the metal cooling from molten to white iron state. Some causes of hot cracks are cores that are too high in baked tensile strength, thin sections cooling more rapidly than heavy sections, and iron in a hard state; the latter is probably the most destructive of the three causes.

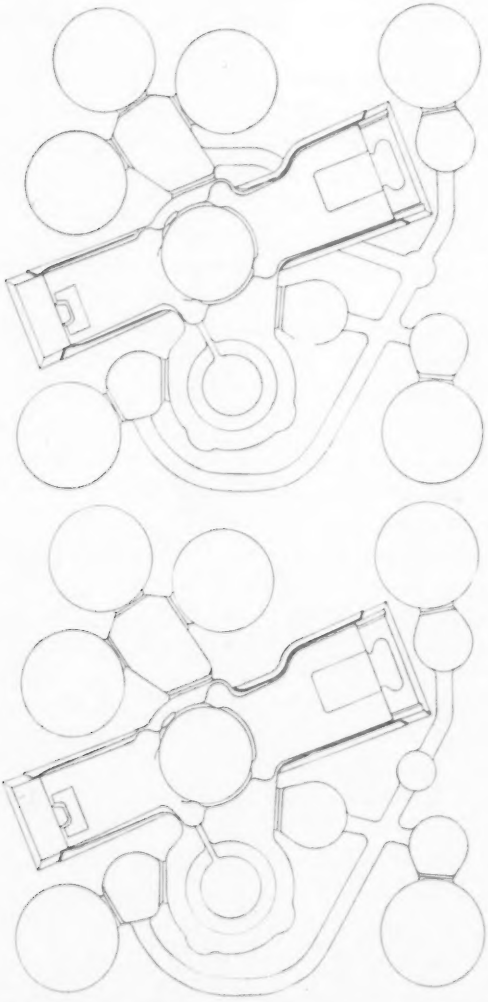


FIG. 1—HANGER CASTING—SHRINKS REMOVED BY USING "BLIND RISER" SHRINK BOSS.

19. Brake and clutch pedals are likely to have hot cracks caused by the heavy bosses adjoining the thin shanks. The pedals also give considerable trouble, having a tendency to crack behind the foot pad. The sketch of Fig. 2 shows one of these castings prior to a revised gating. The cracks were eliminated by adding crack strips at the heavy boss or heavier section. The runners were redesigned (Fig. 3) to a shape similar to an expansion joint on steam lines.

The gate at the pad was raised about 3/8-in. eliminating the crack on the shank.

20. The runners were choked on a one-piece case (Fig. 4) to eliminate cracks, and a carrier was choked and chilled. The sketches of Fig. 4 show the choke and gating arrangements.

21. A large truck carrier, weighing 67 lb., ran 30 per cent scrap at the start of the model. At first considerable trouble was had with hot cracks. Changing the core sand mixture to a lower tensile strength eliminated the hot cracks, but caused the core to wash. The core was then washed with an oil-less core wash, but this caused core kicks. Hot cracks were finally eliminated by adding one additional gate. Trouble was also had with scabs which were running approximately 5 per cent. The scabs were eliminated by adding a ram-up core below the gate. Difficulties were had with the heavy nose of the front of the carrier, battering at the shake-out screen when the mold was dumped. From our first run of carriers the customer had considerable trouble in cleaning up the boss. A chill with a hole completely through the center was made up and used. A piece of paper was glued on one side of the chill

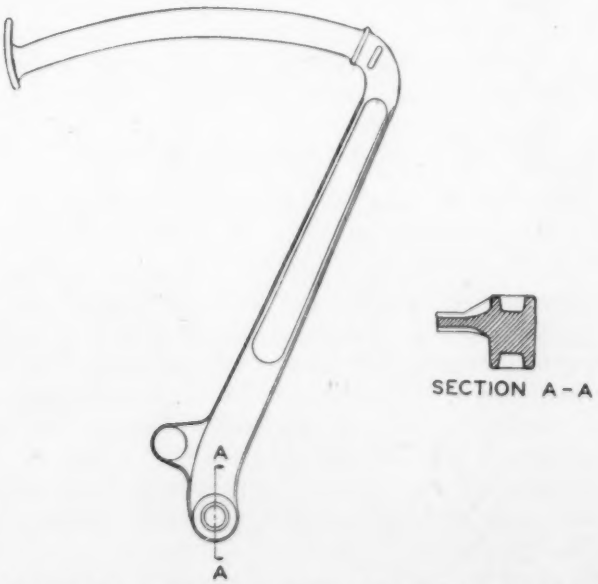


FIG. 2—BRAKE AND CLUTCH PEDAL CASTINGS LIABLE TO HOT CRACKING CAUSED BY HEAVY BOSSES ADJOINING THIN SECTIONS.

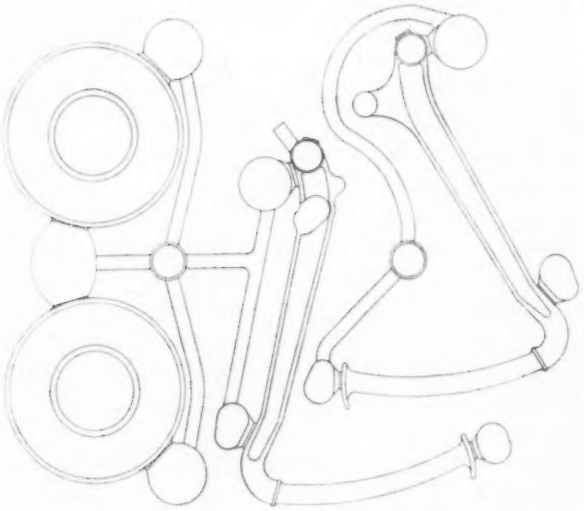


FIG. 3—DESIGN OF GATING OF CLUTCH PEDAL OF FIG. 2 TO ELIMINATE HOT CRACKS.

to prevent sand from plugging the hole when the mold was being made in order that the chill would remain on the casting when poured. The chill then took the battering against the shake-out screen instead of the boss. The sketch of Fig. 5 shows the design of this chill and also the present gating arrangement.

SCABS

22. Scabs are similar to blows and are caused by ramming the mold too hard, or may be caused by the sand being too wet, too high in bond, or the permeability too low.

23. Molten iron flowing over hard sections of the mold or dropping to the bottom of the drag, creates a gas thus kicking and causing a blow or scab. The harder the sand is rammed, the lower the permeability of the mold, and when iron flows over the hard sections the iron will kick off a thin layer of sand. This will occur when the iron is still flowing in the mold. The iron will pick up the loose sand and wash it to different sections of the mold creating a scrap casting. How much dirt or sand is washed into the casting depends on the temperature and rate of flow of the iron.

24. Several jobs in our foundry scab when the sea coal drops below 5.5 per cent, or when the sand has too many fines and the

moisture content is too high. The sand is tested by the laboratory every hour to keep it in good condition at all times. The sand testers must be on the alert to keep the sand in this condition as we run about 120 tons of sand per hour on a unit.

25. Scabs were eliminated in one of our composites by using a ram-up core as permeability is greater. In several other jobs jolting has been reduced and the squeeze head redesigned over the point on the casting showing scabs.

26. A large carrier showed a scab below the gate. At first a ram-up core was used, but the casting still had a tendency to show a slight scab. As 110 pounds of iron was poured in this mold, one more gate was added. This reduced this one gate to one-third of the iron and eliminated the scab almost entirely.

27. Following are several procedures that should be taken into consideration when trying to eliminate scabs:

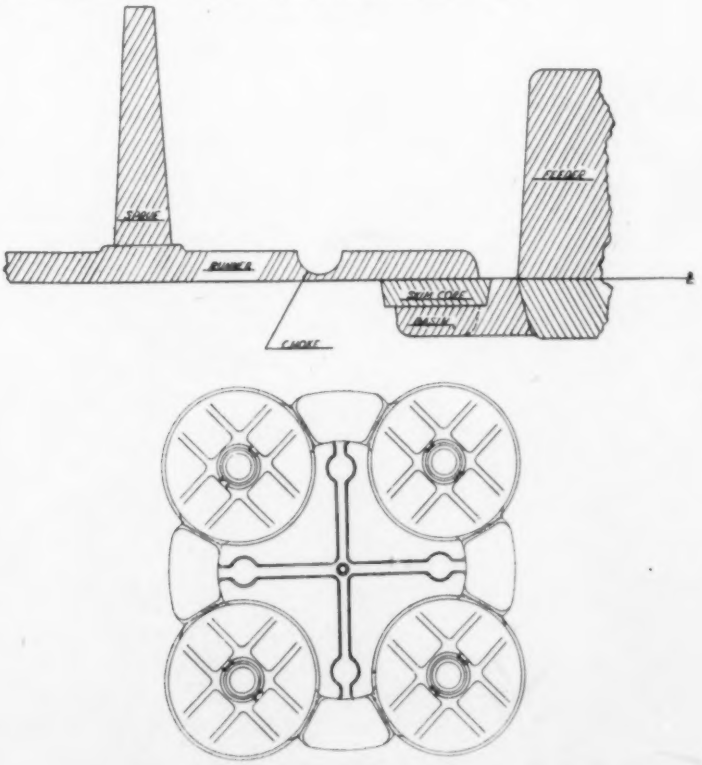


FIG. 4—CHOKING RUNNER TO ELIMINATE CRACKS.

(1) Check mold for hardness.

(2) Too much iron may be flowing through one or more gates. The runners may be choked or another gate added as a remedy.

(3) Check the sand as to per cent of sea coal, permeability, moisture, and per cent and type of clay used.

(4) An almost sure cure on our type of work has been to use a ram-up core.

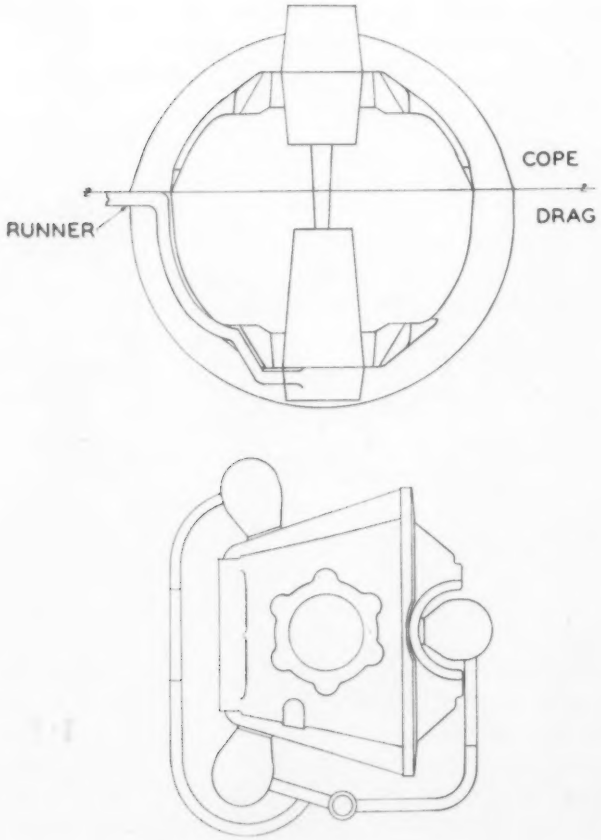


FIG. 5—DESIGN OF CHILL AND LATEST GATING ARRANGEMENT FOR LARGE TRUCK CARRIER CASTING.

Misruns and Cold Shuts

28. The temperature of the iron as tapped from the electric furnace is around 2840°F. All our ladles used are covered or insulated which prevents the iron from losing an excess amount of heat and avoids misruns, which may be caused by the iron being cold.

29. Pattern layouts on all composite equipment should be given consideration as to gating and locating of patterns in molds which will help to eliminate misruns.

30. Misruns may be eliminated, especially on small and thin wall castings, by redesigning the casting or by adding more metal if the customer permits this being done. Regating on some of our jobs has eliminated misruns.

31. Housing patterns were laid out for one sprue for 2 castings. The changing of models in one case caused us to change our entire pattern layout for this housing. A four-on pattern equipment was made up with one sprue for four castings, using a 24-in. round flask. At first the castings misrun. However, the runners were made larger, and a larger skim core was used (Fig. 6) which nearly eliminated the misruns.

32. On a defense job, cold shuts and cracks were the greatest per cent of our scrap. The misruns were reduced by making two

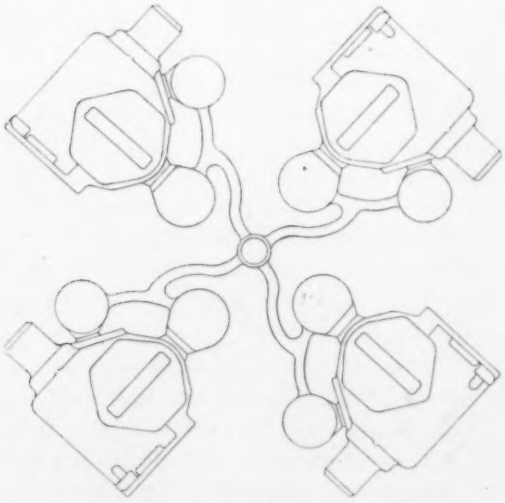


Fig. 6—Housing Patterns Arrangement.

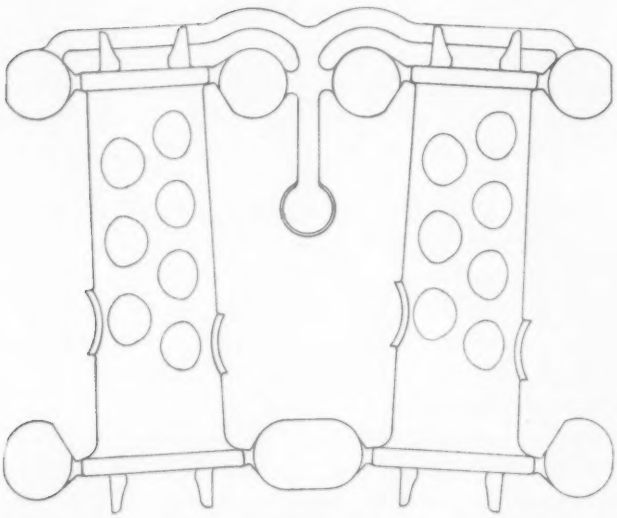


FIG. 7—ARRANGEMENT OF A PATTERN TO REDUCE COLD SHUTS, AND CRACK STRIPS FOR ELIMINATING HOT CRACKS.

bobs dead, and adding crack strips. See the sketch of Fig. 7 for this layout.

33. Because of worn patterns on our hub job, and an increased demand for the adjusting nut, a new composite was made, which contained four hubs and twelve adjusting nuts. The first day the job was run on production, approximately 50 per cent of the adjusting nuts were scrap, due to misruns and cold shuts. A larger sprue post was added but failed, then the size of the runners was increased, but this also failed. The skim cores were left out, with the larger sprue post and runners remaining on the composite, but misruns and cold shuts still existed and the hubs were slagging. The misruns and cold shuts were almost entirely eliminated by choking runners down gradually (Fig. 8) so the hubs and adjusting nuts would fill to proper level at the same time.

34. On a spring hanger casting, the greatest percentage of our scrap consisted of misruns. The number of misruns were reduced by increasing the size of the runners and gates, but the drops increased about 30 to 40 per cent. The original layout had the gates located directly at the center of the pocket, which is shown in Fig. 9. Misruns and drops were eliminated by moving gates to outside of pocket. Some of the causes of misruns are:

(1) Cold iron.
(2) Too large percentage of sea coal in sand.
(3) Improper gating. One and two gates will give better results than three or four if such an arrangement is possible.
(4) Gates and runners too small.
(5) Sprue cup not being hit properly by iron pourer. As a rule the iron should swirl around the sprue cup until mold has been completely filled.
(6) Slag is sometimes the cause of misruns. Our foundry uses teapot ladles so that iron poured into the mold comes from the bottom of the ladles.

Composite Mold

35. One of our composite molds was laid out with two pedals and two hubs, with one sprue for the two hubs, and one sprue for the two pedals. The sketch of Fig. 3 may be referred to as the layout of the composite. At first considerable trouble was encountered with slag collecting at the flange on cope side of both hubs. The runners on the patterns were rearranged several times, but slag still prevailed. A skim core placed both in the cope and drag, with the runners and gates arranged as shown in Fig. 3 entirely eliminated the slag.

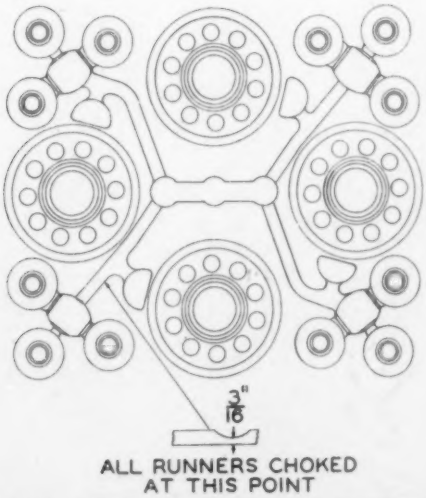


Fig. 8—Eliminating Misruns and Cold Shuts by Choking Runner.

36. Slag also appeared at the gates on the two pedals. The runners were choked, which seemed to increase the slag in No. 1 pedal, and No. 2 pedal showed a misrun. The next step, all chokes were filled in and a skim core was added to the cope. This eliminated the slag in pedal No. 1, but No. 2 pedal still showed considerable misrun.

37. In the sketch of Fig. 3 No. 1 pedal was gated off one sprue. A short runner was used on No. 2 pedal from the hub sprue. This arrangement entirely eliminated the misrun and slag.

CARRIER, CASE, AND BEARING CAP

38. The original layouts of the carrier, case, and bearing cap molding equipment consisted of one carrier to a mold and four-piece cases to a mold. Bearing caps consisted of 12 patterns. At present a composite mold equipment is used with one carrier, one case, and two bearing caps.

39. Carrier and cases were regated several times due to slag lodging in castings at the gate. Chokes were put on the carrier runners. Case runners were also choked. This eliminated the slag in the carrier, but not in the case. The case runner was choked still more, which entirely eliminated the slag in the case, but caused the case to misrun. As the carrier and cap absorbed the iron, after the sprue was full and the iron pourers had gone on to pour the next

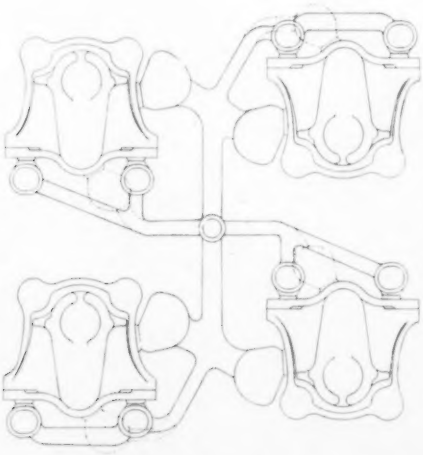


FIG. 9—SPRING HANGER CASTING WITH ORIGINAL GATING, LATER CHANGED BY MOVING GATES TO OUTSIDE OF CASTING TO STOP MISRUNS AND DROPS.

mold, the iron in the sprue would be lowered due to the case drawing iron from carrier and cap, causing the entire mold to be scrap.

40. In our final gating arrangement, a small slab core was made and used as shown in Fig. 10. The agitation of the iron was eliminated by the core, stopping the direct flow of iron from the bob to casting. The iron flowed under the slab core. The chokes in the runners were filled and the slag and misruns were entirely eliminated.

PISTON

41. For a piston casting the core consists of five parts, which are assembled and gauged before being delivered to the foundry. All the core parts are thoroughly vented to prevent blows. All vents are tied in and lead to the back of the core to a main vent fastened to the pattern protruding through the cope.

42. Several methods of gating were tried unsuccessfully before our present method was put into use (Fig. 11). The outstanding problem was to keep slag from forming at the ring grooves. However, it was necessary to keep the gates at the heavy sections to compensate for the shrinkage of the iron. The problem was overcome by extending the runners beyond the ends of the castings in a sharp bend, as is shown in the sketch, and since these runners fill with iron before the castings, they serve as slag traps and keep any slag from forming at the gates.

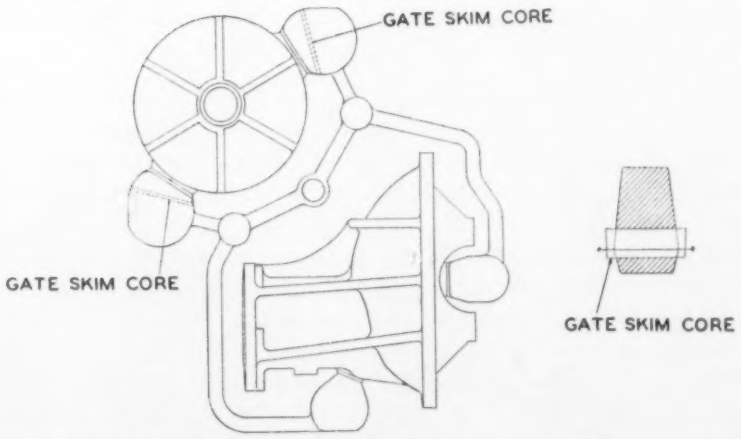


FIG. 10—USE OF GATE SKIM CORE TO STOP DIRECT FLOW OF IRON FROM SHRINK BOB INTO CASTING.

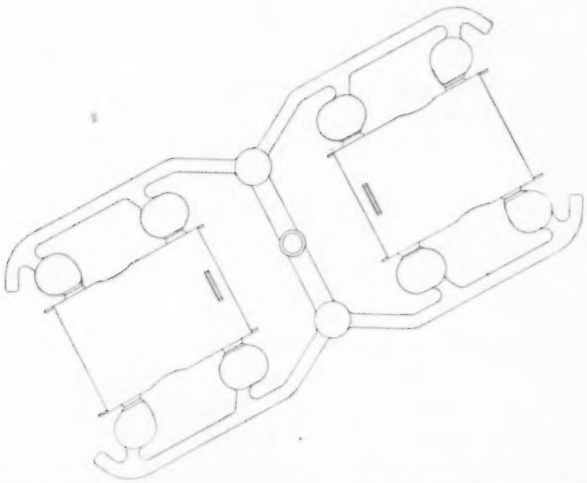


FIG. 11—PISTON CASTING GATING ARRANGEMENT TO ELIMINATE SLAG ENTRANCE.

43. Trouble was also encountered with the sweep cores, chewing or washing at the two front gates. The sweep core is made from a very high tensile strength sand. The chewing of the cores was eliminated by attaching risers to the bobs thus relieving pressure. Scrap was reduced from 35 per cent to about 7 per cent. These pistons are used in diesel motors, and all must pass severe pressure tests before being used.

THREE PART MOLD FOR TRUCK HOUSING CHANGED TO TWO PART MOLD

44. As a rule, our defense truck housing and similar jobs were made in three-part flasks, but due to the present high production rate and the shortage of snap flask stations, a two-part mold, using machine equipment, was laid out. A core was used to eliminate the check part of the mold.

45. The distance between the housing and the flange is about 4½-in. The casting is made up of various light and heavy sections; therefore, a low tensile core had to be used, to overcome the possibility of shrink cracks caused by the core not breaking or burning up properly. The runners had to be enlarged to prevent misruns and cold shuts. Casting the core lightly with silica or oil-less core wash also helped to prevent cold shuts. The gates had to be enlarged to prevent shrinkage, and the breaking point could not be

incorporated, as the flat drier would crush the breaking point on the core. The gate was moved up, and the breaker was added as shown in Fig. 12. The job today is running a fairly low percentage of scrap, and the production was raised to about 3100 in 16 hours on two molding stations. If this particular job were laid out for one housing per mold, and with a three-part snap flask, the number of stations required for the above production would be 23 hand pattern stations or two snap flask lines.

8½-IN. DIESEL PISTON

46. Considerable trouble was encountered with this large piston in the experimental stage due to slag, mottling, misruns, hot cracks, and porous castings. Mottling was eliminated by adding mottle pins (Fig. 13) ⅛-in. in dia., 1-in. in length, and spaced about ¾-in. apart on the dome of the piston.

47. Experimental work was also done with chills. In starting, a thin chill was used, and was gradually changed in thickness until a chill of the correct size was worked out. The light chills did not remove the porous condition in the ring grooves, and a too heavy chill caused chill blows and kicks. The present chill used is 1¼-in. x 1¼-in. x ¼-in. Chills were also added in the dome core in the drag to remove the shrink in the dome.

48. Although crack strips were used around the wrist pin, 30 per cent of the castings still cracked. To avoid misruns the crack strips were made heavier, but the cracks still occurred around the wrist pin. The cracking was entirely removed by placing crack strips within crack strips by sawing into wrist pin core.

49. Chaplets are not used on this job, because they fused

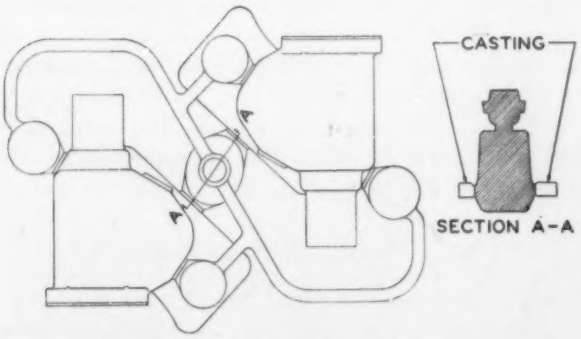


FIG. 12—TRUCK HOUSING PATTERNS AND GATE ARRANGEMENT.

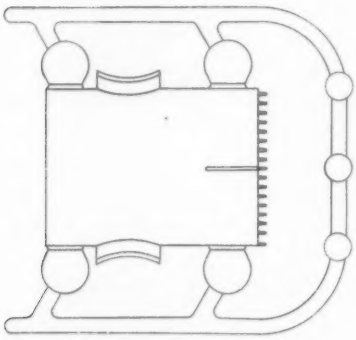


FIG. 13—DIESEL PISTON PATTERN WITH PINS TO PREVENT MOTTLING.

improperly in the casting causing leakers when the castings were tested under pressure. Core supports were installed in the flasks which hold the core in place at wrist pin and base, and no trouble has been encountered with core-offs.

50. Slag was eliminated by extending runners beyond the bobs. The mold was tilted 1½-in. on skirt end to avoid misruns in the ribs of the dome.

51. The molds are allowed to cool 1½ hours to prevent cracking at the skirt end. The core is washed at several places in the drag with an oil-less core wash, to avoid chewing of core and a rough casting surface. Using the above procedure, our piston scrap has been reduced considerably.

TRUCK DRIVE SLEEVE

52. Testing a truck drive sleeve casting with an electrical tester showed that mottling of the casting was running very high. The chills were rammed in the core and were shellacked and sanded after being baked. Dendritic spots appeared in the casting at different intervals, sometimes they were very heavy, also with chill kicks prevailing. The chills were removed from the core and redesigned (Fig. 14) to set in the cope and drag alongside of the thick flange. The mottling and chill kicks were then entirely eliminated.

DOUBLE FLANGED HUB

53. A double flanged hub had been in production for several years in our plant, and had run very well gated as shown in Fig. 15 and using a cup core with two small chills glued into it. How-

ever, with the introduction of ArmaSteel into our setup it was necessary for us to pour iron of about 2.70 per cent carbon. This carbon content, along with method of gating and the size of the bobs, had a tendency to cause shrinks on the flanges at the gates. This condition was remedied by removing the bobs from the small flange, thus leaving the job with gating as shown in Fig. 16.

CAM-SHAFTS

54. Cam-shafts are made four in a mold with two shafts per sprue. At first considerable dirt appeared in all molds along partings. Choking the runners cut down the dirt, but did not remove it entirely. Different facings were tried but failed. The runners were cut down until the castings misrun. Dirt was eliminated by making up a core as shown in Fig. 17. Cores were set in the runner of drag to by-pass the metal to ends of castings, with the metal gradually flowing to the center of mold until the sprue was entirely level.

FIVE PATTERNS ON ONE GATE

55. The casting of Fig. 18 showed internal shrink when cut up and etched. Several changes were made on the casting layout. Larger bobs were used, larger basins, and larger gates, but the shrink was not eliminated. Finally this problem was solved by removing one bob from each casting and leaving only one gate as shown in Fig. 19.

BROKEN CASTINGS

56. Several types of castings are broken due to rough handling, but the greatest number of breaks occur when the bobs and runners are removed. The castings must have a gating arrangement to avoid misruns, shrinkage, hot cracks, etc. Breaking points on all gates should be made in line and at right angles to the bobs and

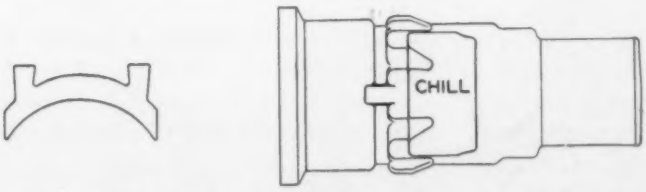


FIG. 14—TRUCK DRIVE SLEEVE CORE WITH PASTED CHILL, AND CHILL USED TO REPLACE CHILL IN CORE.

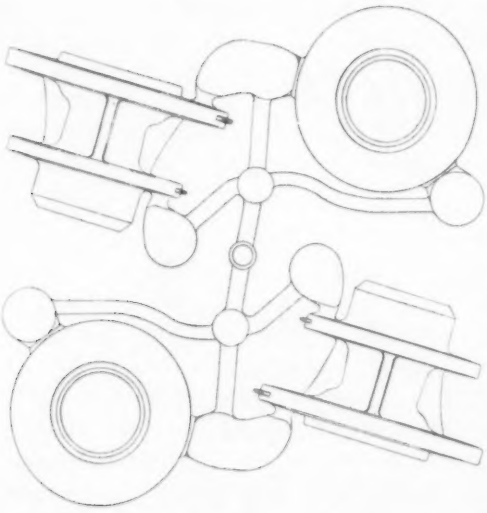


FIG. 15—DOUBLE FLANGED HUB PATTERN SHOWING ARRANGEMENT OF GATES AND BOBS PRODUCING SHRINKAGE AT FLANGES. (SEE FIG. 16 FOR NEW ARRANGEMENT.)

designed to remain back toward the bob as far as possible. Gate pads, as well as fillets, are often used on our castings.

57. Chokes are added (if possible) to the runners on castings having more than one bob or a series of bobs, tied in by one runner, so that the first bobs can be broken off individually, especially where gates and breaking points do not run parallel to the casting. On some of our jobs where the bobs are difficult to break off, larger bobs are used where possible, so that when the mold is dumped on the vibrating shake-out screen, the bobs will break off while hot. This usually leaves heavier gates which increase the man hours in grinding but actual figures show a saving between man hours and the loss of scrap previous to enlarging the bobs.

BROKEN CORES

58. Low tensile strength cores are necessary on several of our jobs which have extremely thin sections. Cores placed vertically in the mold must be held securely in the cope, as well as the drag, or the pressure in the iron will snap the core at its weakest point.

59. Some of our cores, set horizontally in the molds, were cracking or breaking in two. By changing the core print and locators, and tucking cores in at one end pushing the core snug against

opposite end of core print, we have practically eliminated our scrap due to broken and cracked cores. In some cases our cores are reinforced by rods or wires. To some of our core sands we add iron oxide to eliminate cracked, broken, and chewed cores. This oxide gives the sand an elastic effect.

MOTTLED IRON

60. Mottled or dendritic iron is very harmful to the castings and is one of the hardest conditions to detect. At present there is no hard or fast rule to follow in eliminating this structure.

Some of the causes are:

(1) Iron left in the furnace for a long period of time due to breakdowns or holdups.

(2) Weather conditions and chemical compositions of our raw materials.

61. On several of our later jobs, such as cranks, pistons, and all ArmaSteel defense, parts are hooked out at the shake-out to cool individually. The castings then are placed on top of buckets of our conveyor, with other red hot castings where they remain until dumped on the sorting belt. This method has proven entirely satisfactory on these jobs, and also tends to reduce such strain cracks as

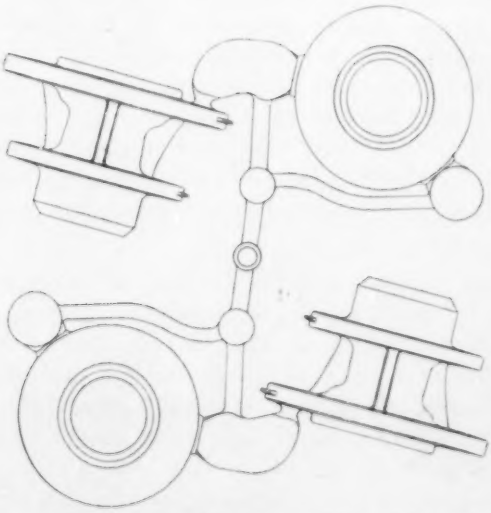


FIG. 16—DOUBLE FLANGED HUB PATTERN—NEW ARRANGEMENT.

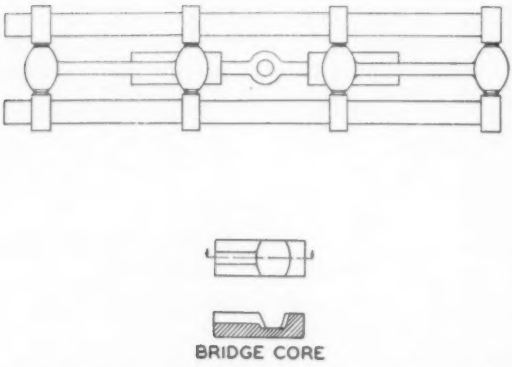


FIG. 17—CAM SHAFT PATTERN WITH CORE TO PREVENT DIRT IN CASTINGS.

might occur in pistons at ribs adjoining wrist pins to dome.

62. Mottle iron can also be prevented by the use of chills, fins, and mottling pins. Cores shaken out from castings as soon as possible will also help to reduce mottling.

CHILL BLOWS

63. Chills at times are very troublesome, causing scrap and considerable expense, due to loss of chill in the sprue, and the cost of preparing and placing them in cores or molds. Chill design should be carefully watched to hold scrap as low as possible. If the chills are too heavy or too light they will blow or stick to casting, causing internal kicks and blows. For good results, chills must be absolutely dry, free of rust, and above all must be properly placed in mold or core. The adhering of chills to castings is prevented by either shellacking and sanding or by dipping the chills in a heavy fuel oil.

64. When transferred to the foundry, the chills should be kept in a warm, dry place or near a gas flame to keep them warm and dry. Chill blows are also caused by the use of oil or alcohol. Chills glued in cores must be absolutely dry and properly shellacked and sanded. Excessive use of red tale should be avoided as it will cause scrap due to chill kicks and chewing of cores. Chills should be placed in a mold, if possible, so they will gradually absorb the heat from the molten iron, which will keep the chill kicks and blows to a minimum.

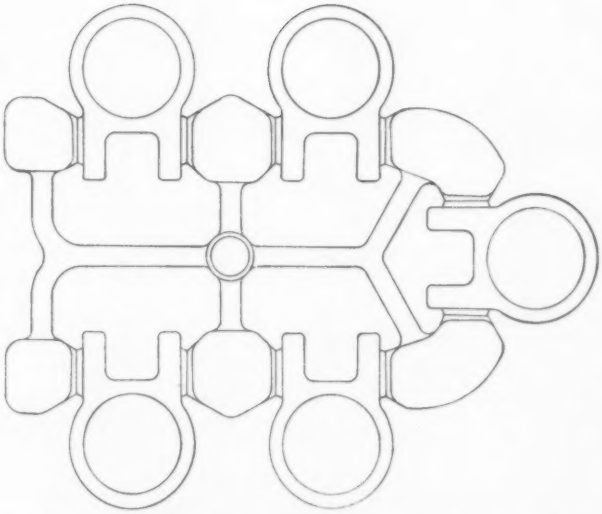


FIG. 18—FIVE PATTERNS ON ONE SPRUE GIVING TROUBLE FROM INTERNAL SHRINKS. (SEE FIG. 19 FOR NEW ARRANGEMENT.)

STRAINS

65. Our new pattern equipment jobs are usually mounted on extra stations in the foundry. Molds are made and checked for crushes, proper matching of cope and drag, etc. The pattern is

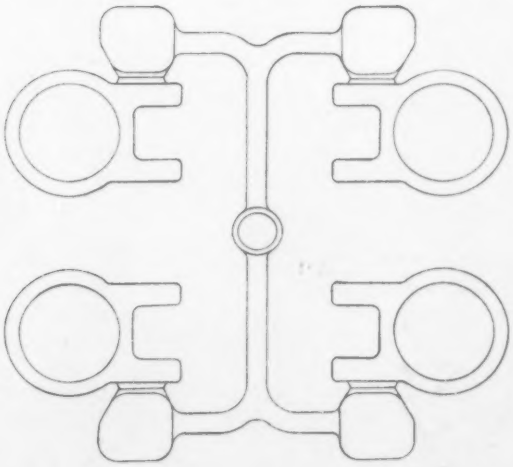


FIG. 19—REARRANGEMENT OF PATTERNS OF FIG. 18 TO OVERCOME INTERNAL SHRINKS.

Table 1

CORE SAND MIXTURES (OCTOBER 1, 1941)

USING THURLOW SAND—DECATUR WHITE FLOUR 13 LB. OR LESS PER CUBIC FOOT GRAIN FINENESS—AFA No. 65 TO No. 70

Type of Core Sand	*Pounds Bank Sand*	*Quarts of Water*	*Quarts of Oil*	*Pounds of Flour*	*Pounds of Bentonite*	*Pounds of Iron Oxide*	*Moist. by Volume per cent*	*Green Compression Strength lb./sq. in.*	*Baked Tensile Strength lb./sq. in.*
Carrier	1050	8.5	5.5	13.5			1.65	1.40	160
Case	1050	6.5	7.0	9.0			1.30	1.20	175
Hi Oil	1050	7.0	15.0	8.0			1.25	1.15	290
Housing	1050	6.0	6.0	7.0			1.25	1.05	140
Skim	1050	6.0	3.1	3.0			1.10	1.00	290
Gate	1050	6.0	2.0	4.5			1.10	1.20	290
Piston	1050	6.0	7.0	8.0		11.0	1.25	1.40	150
Special Carrier	1050	11.0	6.5	13.0	3.5		2.10	2.00	130
Cup	700 Bank 350 Sharp	7.0	16.5	8.5			1.40	1.00	292
Special Housing	525 Sharp	4.0	2.0	7.0	¼ Pt. Ker.		1.3	0.17	130

then removed and taken to the shop where all the faults are corrected.

66. No bottom boards are used on any of our machine line jobs, but all flasks are barred properly to eliminate strained or swelled castings. To avoid drops and runouts the molders must use care in rolling drags over or closing the molds.

67. Automatic timers are used on practically all of our molding machines to insure each mold receiving the correct number of jolts and the correct squeeze. To keep the strains down to a minimum, all the flasks are filled level to the top of the flask and struck off properly after jolting. Several of our castings have ram-offs similar to strains, which are eliminated by use of ram-off strips on pattern. The iron pourer's ladle must be held the proper distance above molds during pouring.

CORE SAND MIXTURES AND FOREMAN ROUTINE

68. Core sand mixtures used in our foundry are given in Table 1 and the daily routine items for our foremen in the foundry are given in an appendix to this paper.

CONCLUSION

69. Production of good sound serviceable castings is a job of every foundryman. If he will take the principles set forth in this report and apply them, he should be able to keep his total per cent of scrap down to a minimum on most jobs.

Appendix

Daily Routine for Foundry Foreman

Foundry

1—Check following items listed: loose patterns—nicks—worn patterns and chill pins—loose or worn steel frame inserts—worn pattern pins and bushings—worn sprue posts or cups—proper date and hour pads—are runners clean of fine or tearup, also gates and pads?

2—Are machines properly shimmed, bumping pads touching, or too many shims under bumping pads?

3—(A) Are machines jolting and squeezing properly?
(B) Slow draw adjusted properly?

4—Are proper flasks being used—check for broken and bent bars, loose bushings and pins.

5—Are proper squeeze heads mounted and lined up properly?
Do blocks touch flask bars?

6—Are machines level on base and dogging level?
7—Are machines properly oiled?
8—Are lines greased regularly?
9—Are molders filling flasks before jolting? Are molds properly struck off?
10—Are carry-out men keeping patterns clear and blowing out drags before they are closed?
11—Are core setters inspecting molds and setting cores properly?
12—Are core passers inspecting cores before they are put on cooler? Are cores clean?
13—Is clamp-up man clamping molds properly?
14—Are iron pourers pouring at proper height for different molds, or bumping molds?
15—Are shake-out men watching for scrap at shake-out?
16—Is sand O. K.—moisture, bond, permeability, sea-coal?
17—Are sand screens working properly to keep cores and other coarse particles out of sand?
18—Is your work area clean and orderly?
19—Have samples been checked on each job?

DISCUSSION

Presiding: C. F. JOSEPH, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

Co-Chairman: R. J. ANDERSON, Belle City Malleable Iron Co., Racine, Wis.

J. H. LANSING[1]: I was interested in the points brought out with regard to reducing the number of feeders and getting as satisfactory results, but in every case, that was due to the fact that you had the metal cooled more slowly in the castings, was it not?

MR. ARNOLD: That is right.

MR. LANSING: In connection with your statement that when you started to pour more ArmaSteel you ran around a 2.70 per cent carbon, was that a higher or lower carbon than the usual run?

CHAIRMAN JOSEPH: I don't believe that was the idea because ArmaSteel is poured from the very same metal that the rest of our malleable is poured. There is no change in the metal, whether it is ArmaSteel or the regular white iron for malleable castings.

MR. ARNOLD: When we started to pour ArmaSteel, we did change the carbon content slightly.

CHAIRMAN JOSEPH: Over a period of time, we have lowered the carbon slightly. Where it used to be 2.80 per cent, we have now gone down to 2.65 per cent and 2.68 per cent.

MR. LANSING: Did you find that lowering the carbon somewhat was as effective as using the cooling fins—that lowering the carbon helped in preventing the formation of primary graphite?

MR. ARNOLD: It helps along the same direction but some of these castings contain heavy, large sections and do need mottling pins. In some

[1] Malleable Founders' Society, Cleveland, Ohio.

cases large fins are used.

MEMBER: Does the use of iron of a high carbon, such as a 2.70 per cent, require less or more feeding than a lower carbon of 2.40 per cent? Does a higher carbon produce the amount of feeding necessary to avoid shrinkage in a casting?

CHAIRMAN JOSEPH: There is no question in my mind that the higher carbon metal shrinks considerably less than the lower carbon metal. In fact, I have seen castings tested that were made of high carbon metal, say 2.60 to 2.80 per cent carbon, compared to a lower carbon iron, around 2.25 per cent carbon, and on the machine, the casting made from the higher carbon iron actually stood up as good as the one made from the lower carbon. It is also true that the lower carbon metal shrinks more than the higher carbon. It has been definitely proved that the higher carbon metal machines easier, shrinks less and feeds better.

MEMBER: In our foundry, before we mechanized and started to duplex the iron, we made a portion of our fittings out of cupola malleable and the larger and thicker sections out of air-furnace malleable. We have pretty definite proof that the higher carbon cupola metal will feed much more readily than the air-furnace metal. Testing under air pressure for soundness, the cupola malleable fittings gave soundness as high as 3.20 per cent carbon, but the air-furnace fittings gave soundness only as high as 2.60 per cent carbon. Every one of them leaked.

MR. LANSING: I think that comparison is one which is really out of line with standard malleable practice. In other words, when we compare a 3.20 per cent carbon with a 2.40, 2.50, 2.60 or 2.70 per cent carbon, the comparison is entirely out of line because we are not comparing the same materials at all. I believe that in the very high carbons there is considerable difference, whereas between the average carbons there is not much difference. Further substantiating that point, there was a test of connecting rod castings carried on under the direction of a committee of the AMERICAN FOUNDRYMEN'S ASSOCIATION. A connecting rod was sent around to eight or ten different malleable plants a number of years ago and was poured in carbon all the way from 2.20 to 2.60 or 2.70 per cent. There was no appreciable difference in the amount of shrinkage.

MEMBER: Is it possible to eliminate mottling by mottle pins?

MR. ARNOLD: Yes. It is a pin about ¾- to 1½-in. long, probably ¼-in. at the base, and tapering off to ⅛-in. at the end. It is nothing but a pin on the casting which makes it cool rapidly.

MEMBER: We also carried that test on the effect of carbon percentage on shrinkage further in air-furnace metal of 2.70 per cent carbon. These particular fittings gave us a nearly perfect percentage of tight fittings. As the carbon went down to 2.50 and 2.40 per cent, we got a greater percentage of leaks. Perhaps there is a difference when we are talking about shrinkage and feeding. The lower carbon iron may not shrink any more, but I feel that the higher carbon metal through the same feeders, which may not be sufficient, will feed better.

W. D. MCMILLAN[2]: We do not have any more shrinkage in the low

[2] McCormick Works, International Harvester Co., Chicago, Ill.

carbon iron than in the high carbon iron. In the change that we made from high carbon to low carbon, we got about 15 to 20 per cent higher tensile strength, not because the iron is that much stronger, but because the casting is that much sounder. The same thing applies to the malleable guards used on mowers. Those castings, as a rule, made from high silicon-low carbon iron are better castings than when made from higher carbon iron.

MEMBER: Then I presume we could take it to mean that the carbon could be dropped at will and we would have no further trouble with the material without changing the gating or anything else in the pattern; we could drop 25 or 50 points of carbon and be just as shrink-free and have as many good castings as we had before.

MR. MCMILLAN: A casting, after all, is what counts. You have got to work on the specific reactions involved. There is not any one rule that you can apply to all castings. I mentioned those two because we did not make any change in the gating, but that would not hold true generally. Iron with 2.20 per cent carbon will not run as freely as iron with 2.60 per cent carbon. Higher silicon increases the fluidity to compensate for the lower carbon, to some extent. However, iron with 1.60 per cent silicon and 2.20 per cent carbon seems to set or freeze at a narrower temperature range than iron of low silicon and considerably higher carbon. This may account, in a measure, for our experience which indicates less shrinkage in this type of iron.

Grinding Wheel Cost Control

By Jeff. Alan Westover*, Cleveland, O.

Abstract

This paper deals with conclusions obtained from a cost reduction and control program on grinding wheels and tells of methods being developed by the manufacturer to insure the constancy of a grade of grinding wheel selected, describing future methods of selection. The author stresses operating conditions as the greatest factor affecting grinding wheel costs, and discusses control factors, such as the condition of the equipment, the condition in which the castings reach the grinder, the grade of grinding wheel and control of the operator. The author considers operator control the most important factor and presents a wage incentive payment plan to establish and maintain such control. Tables and figures are given covering studies of individual methods of work and their effect on grinding wheel costs, as well as standards used in figuring wage payment.

1. The purpose of this paper is to present the relation of conclusions of a cost reduction and control program on grinding wheels that has produced definite results. In 1937, the Burnside Steel Foundry Co., Chicago, with which the writer was then associated, spent an average of $4.26 on grinding wheels for every ton of castings produced. This grinding wheel cost was lowered to $3.61 in 1938, still further reduced to a low of $2.90 in 1939, held at $3.02 in 1940 and controlled at $3.04 in 1941.

Comparison of Costs

2. The work of reducing grinding wheel costs started in 1938 as the result of a compilation of grinding wheel cost figures from foundries in the Chicago-Milwaukee district, and a comparison of our own costs. This gave results as shown in Fig. 1, which is a

* Dyer Engineers, Inc.

Note: This paper was presented at a Steel Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 24, 1942.

graphic curve drawn from the cost records of steel foundries which produced more than 25,000 tons of castings in the period covered. The average weights of castings produced in these plants ranged from the low of 4 lb. in one plant to a high of 200 lb. in another. This curve is not intended to be an exact indicator of what anyone's cost should be, but it will be useful in determining how a plant's grinding wheel cost compares with others in the industry. It would be interesting to know how the grinding wheel costs of those present at this meeting compare with the cost indicated in Fig. 1.

3. Our own cost of $4.26 for 1937, compared with the curve in

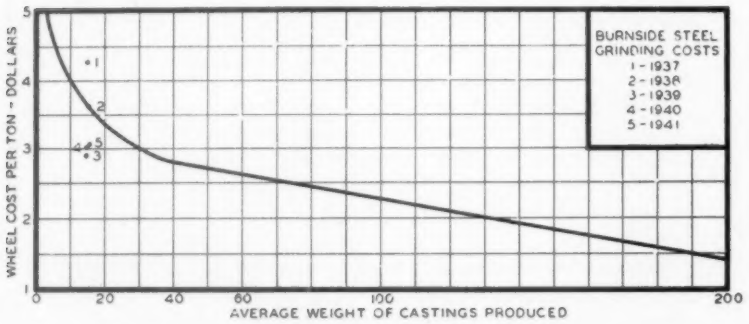


FIG. 1—GRINDING WHEEL COSTS AS COMFILED FROM STEEL FOUNDRIES IN THE CHICAGO-MILWAUKEE DISTRICT COMPARED WITH COSTS IN THE AUTHOR'S COMPANY.

Fig. 1, showed us that we were spending a great deal too much for grinding wheels. This comparison started us on a cost reduction program that, because of the innovations involved, as far as we were concerned, caused us to take a step and then wait till the defects had shown up and been taken out before taking another step. Because of this policy of taking one step at a time, the control described has not been applied to all of the grinding operations. When this control application is finally completed, the grinding wheel cost should be even lower than the $2.90 a ton chalked up in 1939 as the lowest to date. At this writing, it is believed that we have finally reached the end of the trail of defects of any consequence.

4. To begin with, after having decided that this cost item was entirely too high, we notified the grinding wheel manufacturers supplying us with wheels that they were not supplying the same quality of wheel that had been submitted for wheel trials the last time wheels had been tested and a grade decided on. Unfortunately, the grinding wheel manufacturers, at that time and even today,

when an accusation of that kind is made, cannot offer definite proof that their product is still of the same quality as the day a grade of wheel was decided on by a foundry as being the best at the lowest cost for this plant. Neither can they prove that the difference in wheel performance and cost is due entirely to changes in the conditions under which the wheels are operating in a plant today as compared with those existing at the time of the tests.

5. At present, at least one grinding wheel company is endeavoring to solve this problem as a service to the users of its product. The first step will be to make a record of the conditions under which a wheel on test in a plant is operating so that in the future, if the plant should run into trouble, a quick check of operating conditions can be made and compared with the conditions prevalent at the time of the original test. The record is to be made by mechanical recordings of which the graphic ampere record will perhaps be of the greatest value.

Selection of Grade

6. Along the same line of future possibilities is the method by which a grinding wheel grade will be selected. Instead of a manufacturer sending in 3 or 4 different grades of trial wheels to be tested in the hope that in the 3 or 4 wheels he has guessed what operating conditions have to be met, he will come in and find out the physical properties of the metal you are producing. Then, if the physical properties are in the range covered by a performance record, such as Fig. 2, of a grade of his wheels, he can let the user make a choice of a wheel grade that will give him a long wheel life with a comparatively slow rate of metal removal if the labor rates are low, or a shorter life wheel that is a fast metal remover, if the labor rates are high.

7. In other words, the operator will be able to select a grade of wheel that will enable him to have a balanced labor and wheel cost, or a wheel cost that is either higher or lower than his grinding labor cost. After the wheel grade choice is made, the manufacturer will be able to prescribe the conditions under which it must be operated if the expected wheel costs are to be obtained.

8. If the metal's physical properties are not covered by the performance records available, it will only be necessary for the user to submit samples of his material and the wheel company's laboratory can make up the necessary performance record graphs on this metal. This will save the expense of testing wheels every so often to

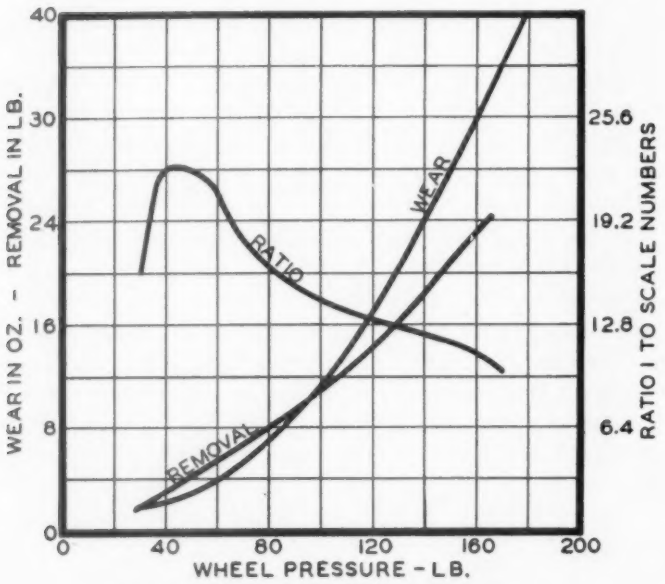


FIG. 2—PERFORMANCE RECORD OF GRINDING WHEEL.

see if the operator has the lowest cost wheel for his shop and yet will enable any manufacturer, if he has made cost reducing developments, to present them in a concrete and comparable manner.

OPERATING CONDITIONS

9. The writer wishes to stress operating conditions as being the greatest cause of widely fluctuating and high grinding wheel costs. Tables 1 and 2 are presented as an illustration of what operating conditions can mean to grinding wheel costs. The operating conditions in these two examples are due entirely to the operators.

10. Table 1 is a record of results of methods used by operators in handling swing frame grinders. Operator 9 was acting on instructions to get the most out of his grinding wheel, getting his work done in the same amount of time as operator 12 whose instructions were to get his castings ground as quickly as possible, and to use as much of his grinding wheel as possible. Previous to and after this test the grinding wheels used turned in practically identical performances on regular production work, yet, during the test, the cost was almost twice as much (1.88 times as much, to be exact), to supply operator 12 with grinding wheels as compared to the cost of supplying operator 9.

11. Table 2 is a record of tests made on a shift of stand grinder operators to determine the fluctuations in wheel costs caused by individual operator working methods on this type of equipment. With the ratio of one pound of wheel used to pounds of metal removed varying from 1 - 3.05 to 1 - 9.44, it is quite apparent that a control of the operators themselves is essential, particularly in view of the fact that the worst and best ratio was turned in by the same operator. The 1 - 9.44 ratio was produced when this operator had the unintentional incentive of taking care of this wheel and making it last until another had been worn down to a size that would fit on his machine. If a wheel to fit the machine had been lacking, it would have been necessary to take the operator off grinding and give him some other kind of work to do. The operator's production rate was practically the same on both wheels.

CONTROL FACTORS

12. Since the control of the conditions a grinding wheel is working under is so important, and the operator controls conditions, it

Table 1

RESULTS OF STUDY OF INDIVIDUAL METHODS OF HANDLING SWING FRAME GRINDERS

Wheel weight at start of test period			85¼	65½
Wheel weight at finish of test period			83¾	62¾
Wheel used (lb.)			1½	2¾
Pattern No.	*Casting Weight Before Grinding*	*Casting Weight After Grinding*	*Operator 9*	*Operator 12*
TS 20061	185½	177	8½	
	182¼	173¾		8½
DX27-35	184½	176½	8	
	179¾	172¾		7
60314	56	55¾	¼	
	56½	56¼		¼
53050HB	66¼	65¼	1	
	65¾	64¾	1	
	66½	65¼		1¼
	66	64¾		1¼
83362H	130¼	127½	2¾	
	133½	130¾		2¾
Metal removed (lb.)			21½	21
Ratio of wheel loss to metal removed			1 to 14.33	1 to 7.63
Figuring wheel cost at 50c per lb., to remove 100 lb. of metal at the above ratios, wheel cost would be			$3.49	$6.55

(Lower cost 53 per cent of higher cost)

is apparent that a control of the operator's methods is of utmost importance.

13. However, there are three other factors that should be taken care of before concentrating on the most important control factor.

(1) The condition of the equipment.

(2) The condition of the castings as they reach the grinding wheel.

(3) The grade of grinding wheel to be used.

Condition of the Equipment

14. The condition of the equipment to which an operator is as-

Table 2

RESULTS OF STUDY OF INDIVIDUAL WORKING METHODS ON WHEEL COST FLUCTUATION

(Check on ratio of wheel loss to metal removed made on stand grinder with operators working on 24 in. x 3 in. x 12 in. high speed wheels.)

Operator	*Ratio*	*Wheel*	*Date*
Ike Smith	1—3.05	....	11.24
Aaron Hayes*	1—3.87	12—12**	12-12
Aaron Hayes*	1—4.47	12—12**	12-11
Otis Williams	1—5.25	12—23	12-26
Ben Holiday	1—5.69	12—15	12-14
Otis Williams	1—6.02	12—4	12-6
Otis Williams	1—6.20	12—4	12-7
Ben Holiday	1—6.39	12—11	12-13
Ben Holiday	1—6.68	12—18	12-18
Otis Williams	1—6.68	11—19	12-5
Ike Smith	1—6.75	12—12**	12-20
Morris Vaughn	1—7.13	12—17	12-22
Aaron Hayes*	1—7.37	12—25	12-27
Morris Vaughn	1—7.64	11—16	11-29
Morris Vaughn	1—7.68	11—8	11-30
Nathaniel Mobley	1—8.64	12—9	12-19
Morris Vaughn	1—8.93	11—21	12-4
Ike Smith	1—9.43	11—11	11-28
Ike Smith	1—9.44	....	11-27
Average	1—6.54	....	....

The best performance was 309.50 per cent better than the worst.
The worst performance was 32.30 per cent as good as the best.

*When this operator is trying to keep up with his partner he is extremely hard on wheels. On 12-27 when his partner was not there, he turned in a performance that was better than the average shown on the above chart.

**This wheel was used by two different operators, showing that even the same wheel in the hands of two operators turns in quite a different performance.

signed is important if the user is to control the amount of grinding wheel used. The grinder must be free of vibration due to mechanical faults because it is a potential destroyer of a grinding wheel as it induces shock loads on the bond of a wheel. This bond, it is well to remember, was developed with two properties in mind—

(1) To hold the abrasive grains together in the form of a wheel against the centrifugal forces that are built up in rapidly revolving wheel.

(2) To break down and release the abrasive grains as they become dull and clogged with molten globules and chips of metal so that the face of the wheel always presents a clean, sharp and abrading surface.

If a bond does its job on a smoothly operating wheel, it will not be strong enough to take the shock loads imposed on it by vibration. Equipment vibration is also a physical strain on the grinding operator, causing low production and excessive labor costs.

15. The operating surface ft.-per-min. speed should be in a range reasonably close to that recommended by the manufacturers. Operating speed affects the operating characteristics of a wheel in such a way that a hard wheel run at a slow speed will show many of the characteristics of a very soft wheel. If one could see how easily and quickly a grinding wheel is shaped up in a slow-turning lathe at the factory, he would realize the importance of running a grinding wheel at the speed recommended by the factory.

16. Stand grinders should have big, adjustable rests incorporated into their design, with provisions for the use of pressure bars or some means other than an operator's hands and body for applying the work to the grinding wheel. This pressure bar should be primarily an aid in keeping the casting firmly against the wheel and in eliminating any chattering. Chattering has an effect on wheel life similar to wheel vibration.

17. A sand box in which the casting can be placed is an excellent chatter- and vibration-absorbing holder when using swing grinders on a miscellaneous run of work.

Condition in Which Castings Reach Grinder

18. The routine of a casting going through the cleaning department is a somewhat touchy subject with most foremen. However, there is a source of possible savings if the castings are not being rough-chipped before grinding. Small, sharp areas, such as nails, vents and fins, because of their small area, have a decided dressing

effect on a grinding wheel. In addition, a casting with ends of chill nails, vents and fins projecting from its surface is harder to handle than one with these projections removed.

Grade of Wheel Used

19. At the present time, it is perhaps best to stick to the grade of wheel being used so that the grinding wheel manufacturer from whom the user is purchasing his wheels can keep him supplied with the same grade of wheel all of the time. However, this matter is one for the user and the grinding wheel manufacturer to decide upon between themselves.

20. Our experience was that we had been using too hard a grade of wheel before we started to control the way an operator took care of it. We had gone to a harder and harder grade of wheel in an endeavor to find one that could take the abuse our grinding operators were giving the wheels in their misdirected efforts to make as much premium as possible on the wage incentive set-up that was being used to figure their earnings. The bond was hard enough in these wheels to keep the dull grains of abrasive from breaking out of the face which made it necessary to use a dresser to keep it clean and in a highly abrading condition. If it is necessary to use a dresser on the face of a wheel to keep it clean, the wrong grade of wheel is being used.

21. Some day we will be able to give the factor of wheel grade being used the attention it should have. Then, as previously mentioned, the foundryman will probably pick out a particular grade of wheel because a study of carefully prepared wheel performance graphs, as shown in Fig. 2, will show that this particular grade will be the best for obtaining low costs. This will be due to its ability to overcome the physical characteristics of the metal and not because the grade of wheel happens to be able to take a lot of abuse from the operators.

22. However, until the user has the opportunity to pick out the best grade of wheel to meet the physical characteristics of his metal, there is no reason why he should not get the most out of his present grade of wheel. If it is used within the range of operating conditions for which it was developed, the cost will be much lower than if it is being misused.

Operator Control

23. Operator control is most easily established and maintained

through the use of an incentive set-up for wage payment. Experience with this type of control, gained in our step-by-step policy, showed that it was necessary to take certain precautions not usually necessary in a wage incentive formula that controls production alone. These precautions are mentioned here separately so that you can take care of them in any wage incentive set-up of your own, if the following formula does not lend itself to your purposes.

24. In Fig. 2 it can be seen that the ratio of metal removed to wheel loss is higher at a low pressure and production rate than at the normal pressure of 80 to 100 lb., and production rate of 8 to 12 lb. of metal removed per hour for this particular wheel. Because of this, it is necessary to establish a minimum rate of production which, if not exceeded by the operator, will cause him to forfeit any premium gained on the wheel-used part of the formula. This is of particular importance in controlling production in a period of decreasing work available because the operators will do the minimum of production work possible, depending on wheel-saved premium to keep their earnings up and the minimum production per hour to keep them working the greatest number of hours.

Figuring Wheel Premium

25. All pieces ground must have an allowance or standard set on them so that due credit may be given in figuring wheel premium. The allowance or standard should consist of two parts—

(1) Actual grinding standard
(2) Standard for handling the casting, equipment or for anything else that is not actual grinding.

If this is not done, it will soon be found that the wheel premium fluctuates widely, and this in turn causes operator dissatisfaction.

26. In figuring the factor for determining wheel premium, compute this on the basis that maximum premium will be earned when a 1 to 23 ratio is maintained. In the formula that was originally developed a ratio of 1 to 17 was used, and this provided a factor that was decidedly on the high or loose side. Metal removal was figured at 35 lb. per contact hour and, using an excellent grade of wheel, it seems to be very close to correct.

MECHANICAL MEANS OF CONTROL

27. While discovering these above cautions, numerous attempts were made to develop a fool-proof set of instruments or mechanical

means of controlling the operator's use of a wheel. Some worked to perfection as long as an observer was on hand, but all proved inadequate for day-in and day-out application. The pressure with which a certain area of the wheel was applied to the work was one of the operator-controlled factors given a great deal of attention. Instruments were developed that would shut off the grinder or indicate in some other way if a predetermined pressure was exceeded. However, a pressure that is permissible on one section of the grinding wheel is ruinous if allowed on another section. A pressure of 100 lb. between the casting and the face of the grinding wheel is all right, but 100 lb. of pressure put on the corner of the same wheel shears off the corner without removing a corresponding amount of metal and raises wheel costs.

GRINDING STANDARDS

28. Table 3 is a portion of a table of standard data used in determining the allowances for grinding off different sizes of oxygen-acetylene cut head and gate pads with a high speed swing frame grinder, using 24 x 3 x 12 wheels.

29. Table 4 is used in conjunction with Table 3 to give the allowances for handling the casting. "Handling" covers the operation of putting the casting on the sand box stand in position to grind the first head pad and removing the casting from the stand. "Reset" covers the operation of shifting the position of a casting when necessary so that other pads can be reached by the grinding wheel.

30. Table 5 is the swing frame grinding portion of a cleaning room specification sheet which can be filled in by a clerk showing the work to be done on a casting. The correct values for doing the indicated work are taken from Tables 3 and 4.

Table 3

ALLOWANCES FOR GRINDING WITH HIGH SPEED SWING FRAME GRINDER

In.	¼	½	¾	*1*	*1½*	*2*	*3*	*4*	*5*	*6*	*7*
½	.11	.15	.28	.30	0.42	0.50	0.65	0.72	0.81	0.90	1.00
¾	.13	.28	.32	.42	0.54	0.65	0.77	0.90	1.03	1.15	1.28
1	.15	.30	.42	.50	0.65	0.72	0.90	1.08	1.24	1.40	1.56
1½	.28	.42	.54	.65	0.77	0.90	1.16	1.40	1.64	1.88	2.12
2	.30	.50	.65	.72	0.90	1.08	1.40	1.72	2.03	2.35	2.67
2½	.36	.58	.70	.81	1.05	1.24	1.64	2.04	2.43	2.83	3.23
3	.42	.65	.81	.90	1.16	1.40	1.88	2.36	2.83	3.31	3.79

Table 4

ALLOWANCES FOR HANDLING AND RESET OF CASTING

Weight of Casting, lb.	*Handling Standard*	*Reset Standard*
10	0.15	0.12
20	0.23	0.13
30	0.30	0.15
40	0.35	0.16
50	0.43	0.18
60	0.50	0.20
70	0.55	0.21
80	0.61	0.23
90	0.68	0.24
100	0.78	0.26
125	0.88	0.30
150	1.00	0.33

31. Fig. 3 is the daily premium ticket on which is recorded and figured the work done by an operator. For purposes of illustration, let us take a casting with two (6 in. x 1 in.) heads and two (1½ in. x ¾ in.) gates, with a weight of 70 lb., to be ground. This information is filled in on the specification sheet (Table 5) and the units of allowance for this work are taken from Tables 3 and 4. This gives us 3.88 units per casting for doing the actual grinding and 0.76 units for one handling and one reset.

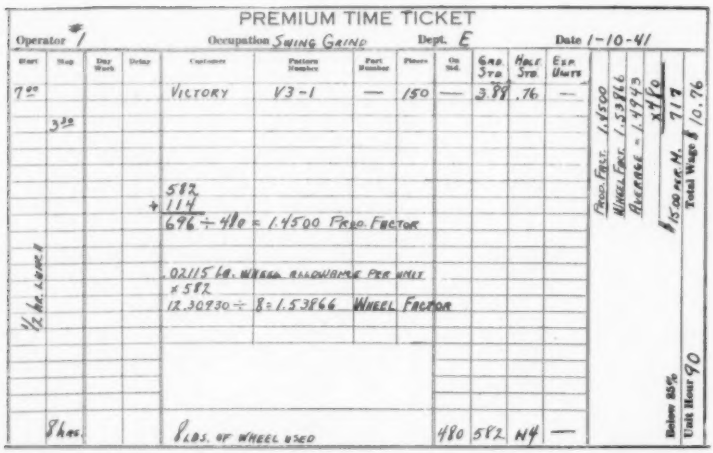
32. The standard of 3.88 and 0.76 units is filled in on Fig. 3, and the product of each of these two figures, multiplied by 150 pieces done in the work period, is carried down to the bottom of the sheet. The sum of these two figures, 582 and 114, divided by the number of minutes on the job which for an 8-hour work period would be 480, gives the production factor of 1.4500. Because this is over the minimum of 1.25, below which wheel premium is forfeited, we will continue and figure the wheel premium.

33. For every unit of actual grinding we have an allowance of .02115 pounds of wheel that can be used. This allowance, multi-

Table 5

SWING FRAME GRINDING SPECIFICATIONS

No.	*Size (in.)*	*Grinding*	*Handling*
2	6 x 1-1.40	2.80	
2	1½ x ¾-0.54	1.08	
	Weight-70 lb.		0.55
1	Resets		0.21
	Standard	3.88	0.76



PREMIUM TIME TICKET

Operator 1 Occupation SWING GRIND Dept. E Date 1-10-41

Start	Stop	Day Work	Delay	Customer	Pattern Number	Part Number	Pieces	Op. No.	Grd Std	Hdlg Std	Esp. Units
7⁰⁰				VICTORY	V3-1	—	150	—	3.88	.76	—
	3³⁰										
				582							
				+ 114							
				696 ÷ 480 = 1.4500 PROD. FACTOR							
				.02115 LB. WHEEL ALLOWANCE PER UNIT							
				× 582							
				12.30930 ÷ 8 = 1.53866 WHEEL FACTOR							
	8 hrs.			8 LBS. OF WHEEL USED				480	582	44	—

½ hr. Lunch

PROD. FACT. 1.4500
WHEEL FACT. 1.53866
AVERAGE = 1.4943
× 480
717
$15.00 PER M.
Total Wage $ 10.76
Below 85%
Unit Hour 90

FIG. 3—DAILY PREMIUM TICKET.

plied by the 582 grinding units, gives us a figure of 12.3093 lb. of wheel. We will suppose the operator for this particular day's work actually used 8 lb. of grinding wheel which divided into the wheel allowance, 12.3093, gives us the wheel factor of 1.53866.

34. The sum of 1.4500, the production factor, and 1.53866, the wheel factor divided by 2, gives us 1.4943, the average or combined factor of production and wheel used, and this combined factor of 1.4943, multiplied by 480, the minutes of time on the job, gives us 717 units, the number of units of work for which we are willing to pay the operator. This figure, multiplied by $15.00 per thousand units, gives us the operator's pay of $10.76 for the day.

35. In actual practice, it is recommended that the wheel part of the formula be figured only once a pay period and that the operator be told only the number of units to his credit from day to day for the grinding and handling, so that in case too much wheel was used, it is only so many units forfeited and not so many dollars and cents of pay.

36. The above information and opinions are not to be construed necessarily as that of the writer's associates or others connected with the experimental work.

37. It is hoped that the preceding information may be of use in enabling others to use the fastest cutting wheel obtainable and in helping conserve the materials which are needed to speed Victory.

DISCUSSION

Presiding: R. A. GEZELIUS, General Steel Castings Corp., Eddystone, Pa.

Co-Chairman: H. D. PHILLIPS, Lebanon Steel Foundry, Lebanon, Pa.

W. O. SMITH[1]: What kind of steels were these tests made on? There certainly must be some variation in armor as compared to a common Class 2 steel.

MR. WESTOVER: These tests and this control were on an ordinary low alloy carbon steel, in most cases. There is a difference in the grade of wheel needed for metals of different physical properties.

MR. SMITH: Such as 1.25 per cent manganese?

MR. WESTOVER: Yes, possibly there would be some manganese steel in there. It was all low alloy, whatever it was. The two charts that were shown as laboratory reports were on a stainless steel.

MR. SMITH: An 18-8?

MR. WESTOVER: I am not sure about that. They didn't give me the analysis of that steel. They said it was a stainless steel of fairly high Brinell hardness. They found they had to vary the grading of the wheel to meet a particular physical property of that steel, but they could duplicate almost exactly the performance record from one steel to another by varying the different grades of the wheels.

MR. SMITH: One of those first charts showed variation of operator performance from day to day. Were all of those day-to-day figures on one grade of steel or similar grades of steel?

MR. WESTOVER: They were on similar grades of metal and were all on the same grade of wheel. In other words, they were using one grade of wheel for all their grinding.

MR. SMITH: Then how about the type of job you are running from day to day?

MR. WESTOVER: That varied somewhat, but, on days when the record was almost exactly the same for the different operators, they were handling the widest variation of work.

MR. SMITH: Miscellaneous material?

MR. WESTOVER: They were miscellaneous castings just as they happened to come through these sets of stand grinders. We found it did not make any difference what the casting was, as to size or shape, if we were measuring the work in a way that indicated *exactly* what that work was, and that is why we had to go to our wage incentive measure to set up all of our formulas for controlling the operators because this measure gave us an indication of what the operators were actually doing.

MEMBER: How did you determine and keep the pressure the man was applying on the swing frame grinder?

MR. WESTOVER: To find out what the actual pressure was, we weighted the handles of a swing grinder to give us a definite weight there. We put a scale under the wheel at the same level at which the casting would be, and in that way we found out the weight at which the wheel would be coming down on the casting. Then we took an am-

[1] Smith Steel Foundry Co., Milwaukee, Wis.

meter reading of the motor and that ammeter reading, in turn, told us whether we were continuing that same pressure through the duration of the test period.

MEMBER: What did you do about the inconsistencies of grinding wheels?

MR. WESTOVER: That is quite an interesting subject in itself. We found that our grinding wheels coming from the different sources of supply were, on the whole, *very, very* consistent. We did have a couple of occasions where we ran out on consistency of wheels but it was very noticeable and the operators called it to our attention. On the whole, using the one grade of wheel from a certain manufacturer, we would duplicate on laboratory checks by taking a head and grinding on it for a certain period with the grinder weighted for a certain pressure. We could duplicate from time to time the performance of the grade of wheel which we were using.

MEMBER: What bonded wheel did you use to make these tests?

MR. WESTOVER: High speed resinoid. We also tested some rubber and some vitrified wheels but most of the work was done on the high speed resinoid bonded wheel of aluminum oxide grit.

R. ERWIN[2]: Did you find any variation in the high speed resinoid bakelite wheels compared with vitrified wheels in your cost control or tests? In making your test, was the outcome about the same on a high speed wheel compared with a vitrified wheel?

MR. WESTOVER: We went to a high speed wheel because we decided that was the kind we wanted to use from production standpoints. We then concentrated on finding the wheel that would give us the satisfactory ratio of metal removed to pounds of wheel lost when it was used correctly.

MR. ERWIN: Would the different pressures actually break down one wheel faster than the other? If you applied more pressure to a high speed wheel would you break a vitrified wheel down faster or would you break a rubber or bakelite wheel down faster, or did you go to that extent?

MR. WESTOVER: We decided that a rubber wheel was not suitable for our work and that we were burning out the bond on those by the amount of pressure we were using. The grinders more or less pick out the pressure at which they want to work, and that pressure was such that the rubber bonded wheel burned out. As to bakelite or resinoid and vitrified bond, you get comparable results either way.

MEMBER: How low could you go effectively in your speeds? I take it these wheels were running at 9000 ft. per min.

MR. WESTOVER: We were up around 9500 ft. per min. whenever we could be. We went down as far as 4000 ft. per min. with a high speed resinoid wheel, and at that low pressure we had to go extremely light as to pressure. In other words, one factor influences another. If the wheel speed is dropped, the pressure must be decreased. If the pressure is picked up, the wheel speed must be kept up to get the same perform-

[2] National Malleable & Steel Castings Co., Cleveland, Ohio.

ance out of that wheel and within the normal operating ranges of a wheel. From 9500 ft. per min. down to about 8000 ft. per min., we found no material difference that the operator could not easily compensate for in the way he handled that wheel.

MEMBER: Were these tests made by weighting the swing frame grinder, or was there an operator operating the frame?

MR. WESTOVER: We found the pressure at which the wheel was being operated by weighting the grinder, and then we found out what the ammeter recording was. Then we turned the machine over to an operator and asked him to stay within a certain range on the ammeter.

MEMBER: Do you think there might be a tendency on the part of the grinder to baby his wheel and thus curtail his production?

MR. WESTOVER: That is a very, very definite thing that does happen. We had to change our formula after we had been in operation with it for some time. In paragraph 24 of the paper it is mentioned that we had to insist that at least a certain minimum production was maintained before any premium at all would be paid on a wheel. The operators found that they could maintain their earnings by taking all of their premium on wheel savings and do just enough work to get the required amount of wheel saving. In other words, they kept busy just as many hours in a day or a week as they could by going very easy on the grinder and made the wheel premium, giving them the entire premium earned.

MEMBER: What allowance does your system make for the factors of labor and overhead in connection with your wheel ratio and wheel wear? Certain wheels give you the same ratios but another wheel will do it faster. What allowance do you make in the factors of your cost? You are saving wheels but how about the final cost of metal removal?

MR. WESTOVER: The management has to decide as to what the production rate should be, and then wheel control is figured after the production basis is set up.

MEMBER: Did you find any variations along that line? Certain wheels save less but do the work a lot faster than others.

MR. WESTOVER: Very definitely. The wheel we finally selected gave us our fastest metal removal with the wheel ratio we decided was suitable for our operation.

MEMBER: What ratio did you find between cost of wheels and cost of labor involved? Have you any figures on that? In other words, what percentage of your grinding cost and cost of wheels is there as compared to your total cost of grinding and wheels together?

MR. WESTOVER: We finally worked out a ratio of 1:1. The material cost was about the same as the labor cost. Under certain labor conditions, for instance, management may decide that they want to go to a wheel that gives them a very low wheel cost and they would just as soon have their operators stay on more hours. They go to a wheel that gives a very high ratio of metal removed to wheel wear. It is going to be a slower cutting wheel. It is going to take the operators longer to do a particular piece of work. By changing the formula to meet the condition

you can keep your operators on and yet come out with about the same total cost in the end.

MEMBER: What is the cost of gathering that data from day to day?

MR. WESTOVER: The operators are allowed fifteen minutes a day on the swing grinders and ten minutes a day on the stand grinders to have their wheels checked in and out.

MEMBER: If you had a jobbing shop, would you have to have a checker on every job?

MR. WESTOVER: We had our wage incentive system and we utilized the same checkers to do both.

MEMBER: For all the grinders?

MR. WESTOVER: Yes. There was a combination of a checker who worked as an inspector to see whether a casting had need of a weld and he also filled in the premium time ticket.

MEMBER: That would mean a checker on each shift?

MR. WESTOVER: Yes, we had that previously, anyhow, for the wage incentive system that was being used. We had to allow the operators a few minutes longer, but that was the only additional cost.

MR. ERWIN: Is there any difference in efficiency of grinding when you set your rest at different points, below the center of the wheel or exactly at the center or above the center? Is there any difference in the wheel cost if the rests are set at different points?

MR. WESTOVER: Very decidedly. The result will be the same action as a lathe if the rest is down too low, or, going the other way, the production is kept down.

MR. ERWIN: Where would be the most efficient point to do the grinding of fairly large castings?

MR. WESTOVER: I would say almost straight out, although that is a question that the grinding wheel representative can answer best for you, because most of them have very decided ideas as to what is the best for their particular kind of wheel and it makes quite a little difference in the bond and the grain size.

Statistical Methods as an Aid to the Control of Foundry Operations†

By H. H. Fairfield*, Ottawa, Ont., Canada

Abstract

Statistical methods are discussed and outlined and various data applying to gray iron foundry work are given. After showing the value of analysis of operating data, a plea for more general use of the statistical method is made.

1. Every foundryman is concerned with the prevention of scrap castings. Unanimity of opinion as to causes of foundry losses does not prevail. Schwartz[1] has stated, "A vast deal of inconclusive argument goes on in foundry circles as to the effect of (say silicon) on foundry losses." He goes farther and points out that incorrect conclusions frequently are drawn from scant data, or from data which may or may not have any relation to the occurrence of scrap. Any one who has been connected with foundry organization is familiar with these endless arguments as to the cause of foundry losses.

2. To prevent foundry losses, it may be assumed that the goal to achieve is perfect foundry practice. Although great advancement has been made in the general quality of castings and efficiency of production, it is well known that foundry practice varies considerably from shop to shop. Many instances are known where a practice, which was perfectly satisfactory in one foundry, produced heavy losses when introduced in another foundry. Nichols[2] has shown the wide variation in molding sand practice and pouring temperature that exists between automotive cylinder block manufacturers.

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†Presented by permission of Director, Mines and Geology Branch, Department of Mines and Resources, Ottawa.

*Metallurgist, Metallic Minerals Div., Bureau of Mines, Mines and Geology Branch.

[1]Superior numbers refer to references at end of this paper.

Note: This paper was presented at a Gray Iron Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 24, 1942.

3. We must concede, therefore, that although there are certain well-established and widely used principles of gray iron casting, each foundry is forced to adopt slightly different practices to operate the most economically and make good castings. When scrap castings occur in a foundry, the cause or causes must quickly be corrected. Steps which may be taken are:

(1) Changes in practice, trial and error system, guided by previous experience.

(2) Changes in melting, molding, or sand practice, making use of published data on foundry practice.

(3) Statistical analysis of operating data in order to determine the best operating range for all measurable factors such as analysis, mold hardness, pouring temperature, etc.

(4) Deductive reasoning, new methods, new materials and new equipment.

4. McFerrin[3] and Tour[4] have shown in excellent fashion the

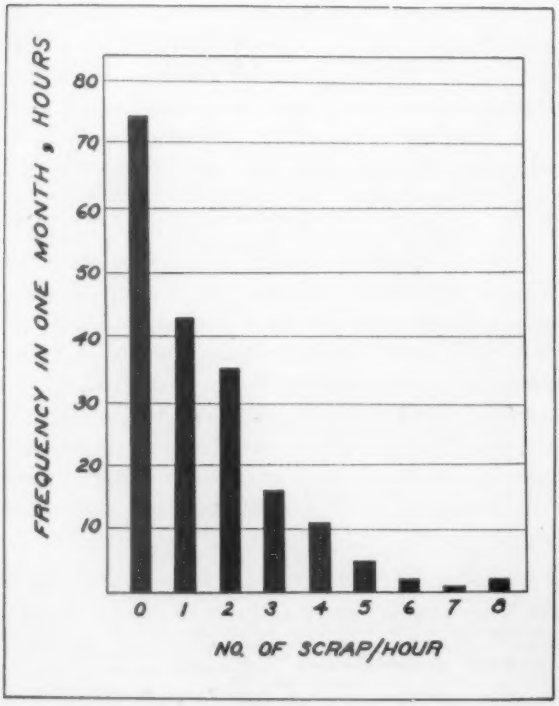


FIG. 1.

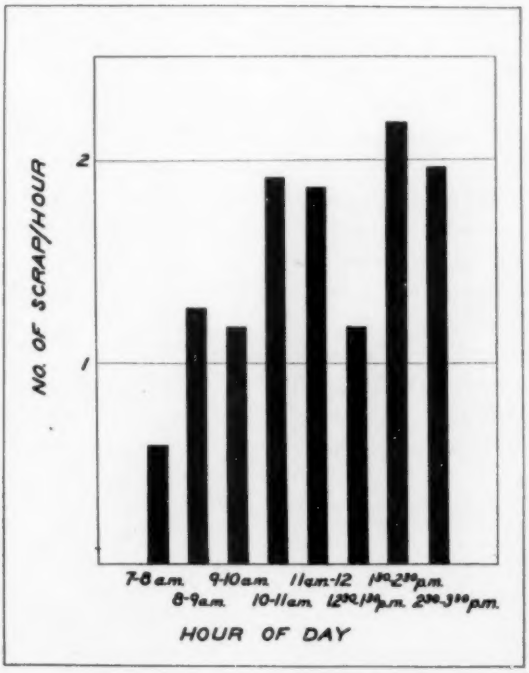


FIG. 2.

many practical considerations involved in correcting the causes of scrap castings. Dwyer[5] has pointed out the role played by designs of gates and risers in the foundry.

5. A great volume of literature sets forth the recommended methods of foundry operation. Austin[6], Reese[7, 8], Massari[9], and others have pointed the way to better cupola operation. Dietert[10, 11, 12], Valtier[13] and Woodliff[14] have provided a vast amount of information on molding and core sands and their properties.

6. Even with all of the above information at the disposal of a foundry operator and with complete facilities for testing materials, the problem still remains to be solved: What is the most desirable operating range for each measurable factor?

7. A question of this nature can be answered by using statistical methods. While it is true that we learn by experience, in a foundry so much goes on at once that an observer may never realize the connection between two events, whereas an analysis of records kept over a short period of time would reveal the correlation. This idea has been mentioned by several authors, including Sam Tour[14],

Schwartz[1], Reichert[15], and Dietert[16]. Corson[17], in discussing the errors inherent in foundry experiments conducted outside of the production department, states:

> "Mass production of research data is the only method by which the general processes can be made clear and freed of antiquated or ill-substantiated notions."

8. Statistical departments have been in operation in steel mills and manufacturing industries for many years. Schrock[18] has shown how statistical investigation has made possible:

(1) Improvement in steel quality.
(2) Fewer rejections.
(3) Reduction of operating costs.
(4) A more exact knowledge of the effect of each operating condition (for example, the amount of lime charged into the basic open hearth) upon the quality of the finished

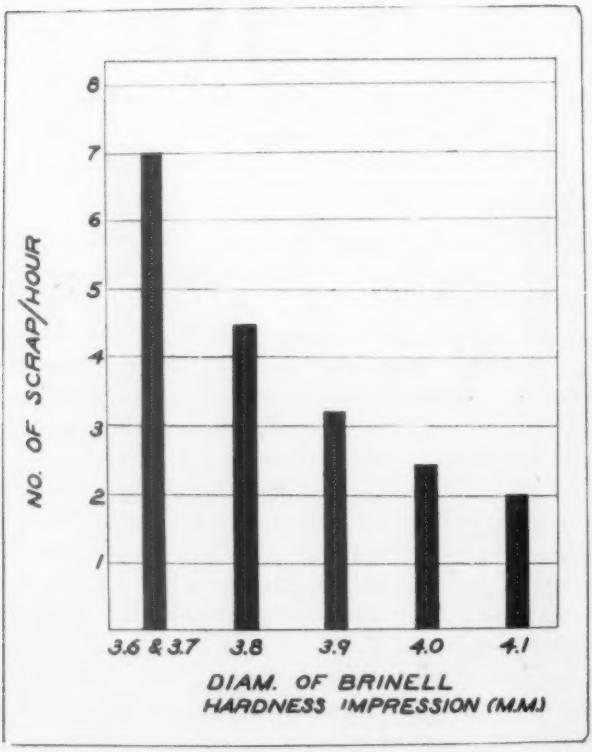


FIG. 3.

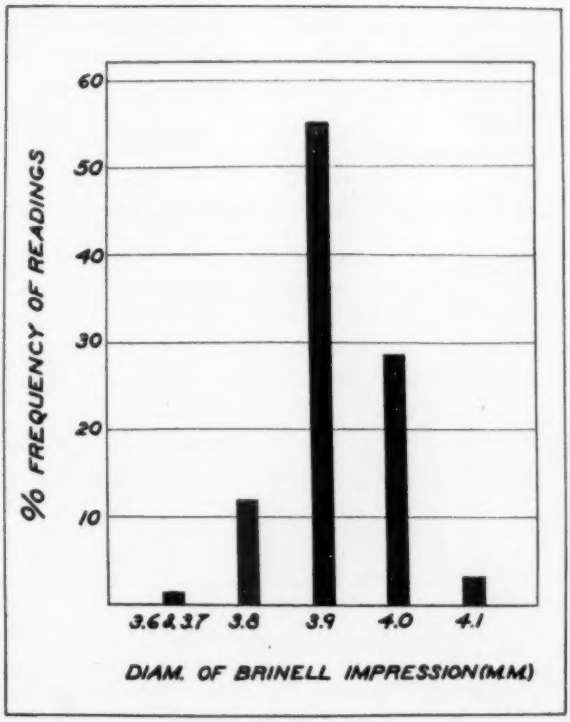


FIG. 4.

product (per cent of rejected steel tubes and chipping costs).

9. The *Metal Industry*[19] states: "Now that metallurgy has more or less progressed from an art to a science, the time seems ripe to enquire how and in what fields the methods of the statistician can aid the metallurgist." It is suggested that a new specialist is appearing who might be termed a metallurgical statistician. Chalmers[20] discusses the use of non-destructive tests which have been found to be related directly to destructive tests. It is necessary to use statistics in order to determine the relationship between two types of tests on the same material.

10. Since the value of statistical methods to many industries has been well established, the author concluded that this valuable tool should again be brought to the attention of foundrymen. The practical foundryman is interested only in obtaining maximum production, satisfactory quality, and minimum cost. Therefore, a statistical program should have as its objective one or more of these.

Three practical techniques which the foundryman will find of great value in analyzing large amounts of test results are:

(1) Determination of quality level.
(2) Correlation.
(3) Statistical control charts.

QUALITY LEVEL—GENERAL CHARACTERISTICS OF PROCESS

11. Frequently it is desirable to know if a certain casting is representative of the average run of castings. When a change in gating, method of molding, or metal composition is made, the management wants to know what effect this change has made upon the product. If the quality level is not known, as is the usual case, erroneous conclusions are frequently drawn.

12. Quality level consists of the measurements of the desirable property under standard conditions of test. It may be expressed

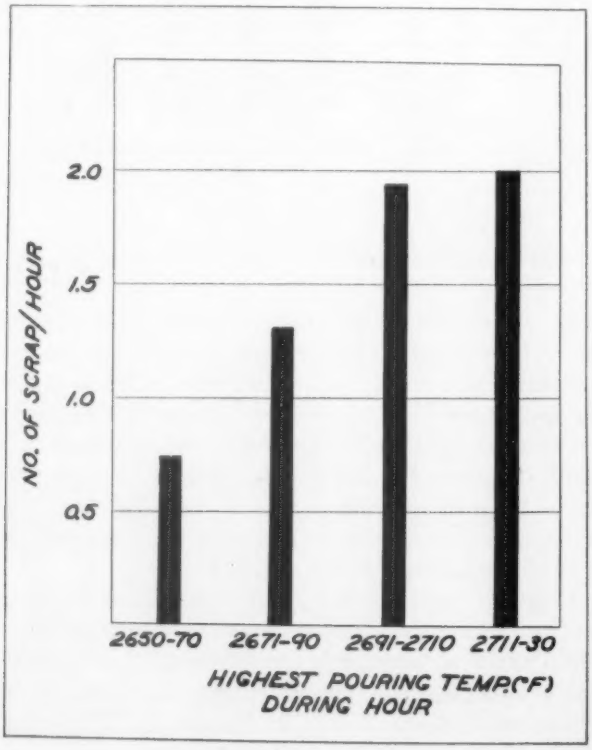


FIG. 5.

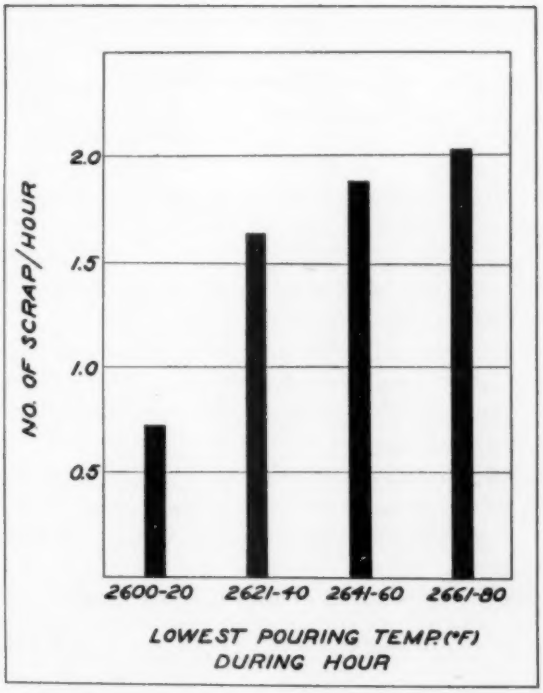


FIG. 6.

in terms of breaking load, hardness, smoothness, soundness, etc. Pages and tabulations of figures are difficult to interpret without some statistical aids. The test results, therefore, are considered as a distribution which may be described by the following terms:

$$\text{Average} = \frac{\text{Sum of results}}{\text{No. of results}}$$

$$\text{Standard deviation} = \sqrt{\frac{\text{sum of (each result minus average)}^2}{\text{No. of results}}}$$

$$\text{Relative Skewness}^* = \text{Sum of } \frac{(\text{each result minus average})^3}{\text{No. of results}}$$

$$\text{Relative Kurtosis}^* = \text{Sum of } \frac{(\text{each result minus average})^4}{\text{No. of results}}$$

* These values are significant only when derived from several thousand test results.

Number of results should always be stated so that the probable error can be estimated. More weight naturally attaches to larger samples. Other measures of central tendency besides average are occasionally used.

Standard Deviation

13. This value is probably the most valuable statistical "yardstick." Its significance is roughly as follows:

(a) For any group of test data studied, Average ±3 Standard Deviation will contain at least 88.9 per cent of all the results (Tchebycheff's theorem).

(b) If the value studied occurs in a normal distribution, then at least 99.7 per cent of the results will fall within Average ±3 Standard Deviation (Gauss). This condition is known as "in statistical control."

(c) Results falling outside of Average ±3 Standard Deviation are generally assumed to occur as a consequence of some change in the environment producing the objects being tested.

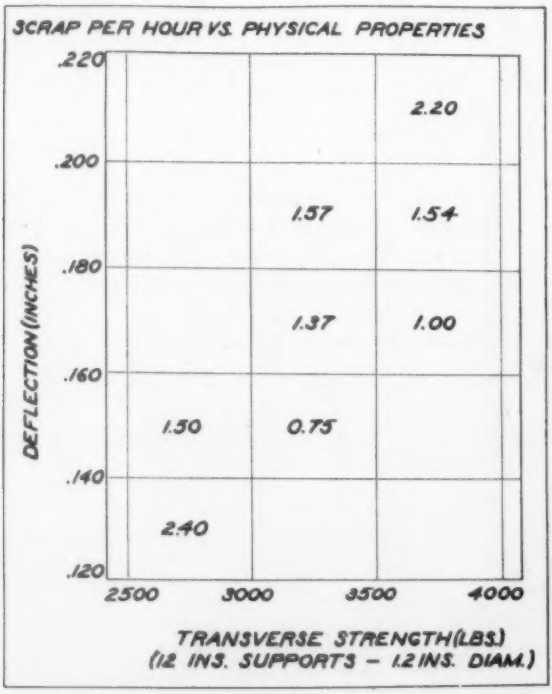


FIG. 7.

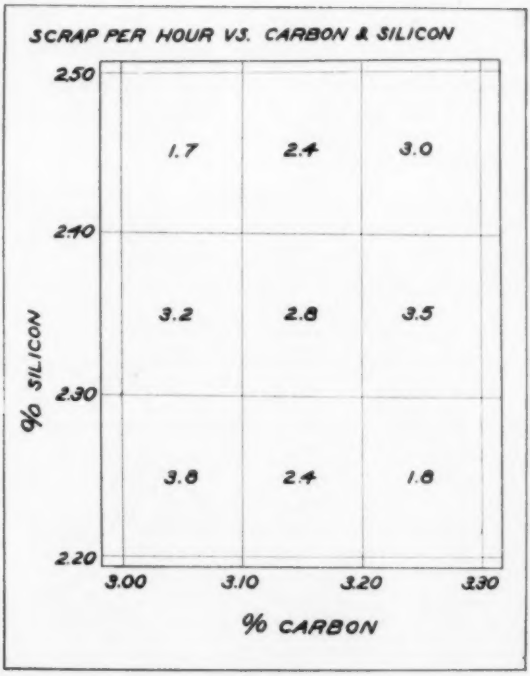


FIG. 8.

These results can be singled out for intensive investigation as to their cause. Variations within Average ± 3 Standard Deviation limits are due to the nature of the process and cannot be changed without changing the process. Thus, standard deviation can be used to tell whether it is best to leave well enough alone or whether corrective action is needed.

Skewness and Kurtosis

14. A normal distribution has results distributed symmetrically about the average and the skewness factor therefore is 0. In actual practice there is usually some variation from the perfect normal curve. This variation is given a quantitative measurement by obtaining the skewness and kurtosis factors. However, unless test results number over 9,000, frequency distribution charts give a better picture of the distribution of results.

Frequency Distribution

15. Frequency distributions are obtained without any calculations and provide an excellent means of graphically portraying a large number of test data.*

Probable Limits of Error

16. The accuracy of measurements of average and standard deviation is naturally dependent upon the number of results. The probable error of an average can be expressed as:

$$\text{Average} \pm \frac{3 \text{ standard deviations}}{\sqrt{\text{No. of results}}}$$

Standard deviation will be expected to vary due to chance alone within:

$$\text{Standard deviation} \pm \frac{3 \times \text{standard deviation}}{\sqrt{2 \text{ No. of results}}}$$

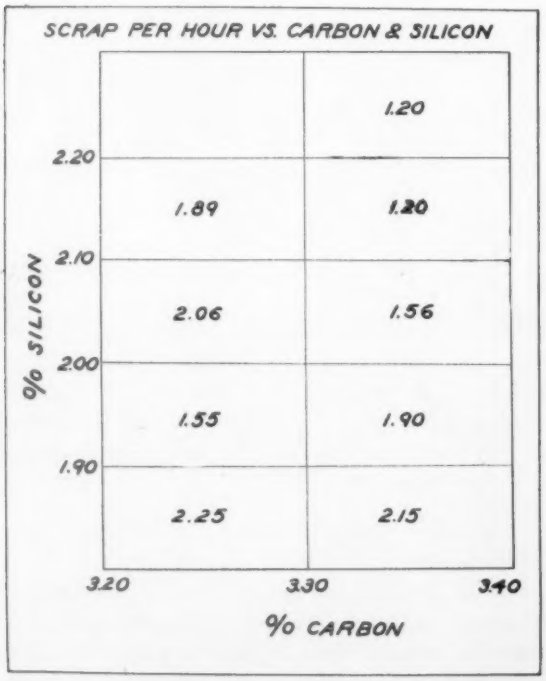


FIG. 9.

* *"Symposium on Malleable Iron Castings,"* American Society for Testing Materials, and American Foundrymen's Association, pp. 42-43. METALS HANDBOOK, American Society for Metals, p. 155. MANUAL ON PRESENTATION OF DATA, American Society for Testing Materials.

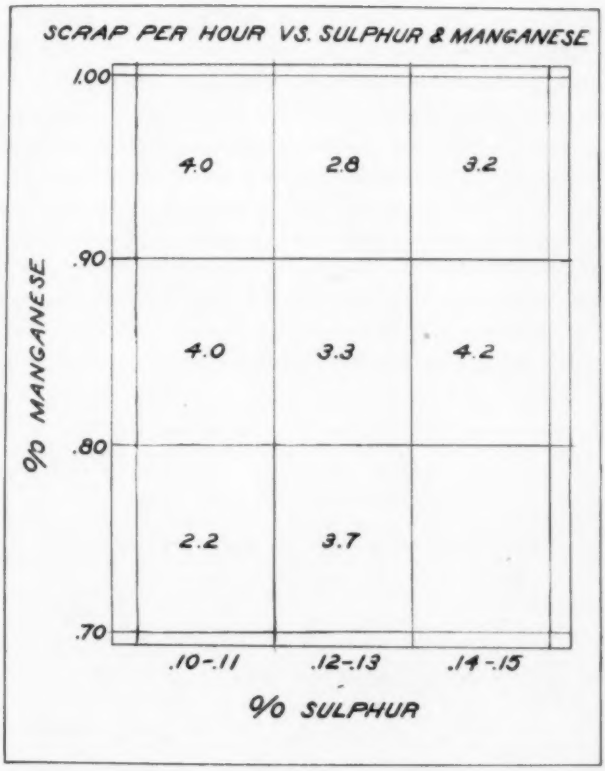


FIG. 10.

17. In comparing two groups of data in order to find out if there is any real difference between them, it is first necessary to find within what range successive samples from the same universe would be expected to occur.

18. A great many test records can be analyzed profitably by comparing quality levels for different time intervals. For example, control over moisture content of molding sand is always a vital problem. Assuming that the optimum moisture content is known, the foundryman wishes to know if this property has changed from hour to hour, also whether or not the deviation from average is indicative of normal operation. This is where the quality control chart can be of great service. It shows very clearly when normal variation is exceeded.

19. To compare the results of two periods of operation without drawing false conclusions, it is almost necessary to use the concepts of quality level. A level of quality may be measured and defined, but control over quality is inherent in the methods of manufacture. If the methods of manufacture remain constant, no change in the quality level of the product can take place. If the quality of the product changes, it may be assumed that some change in the process has taken place. When a foundryman runs into a lot of porous castings, he may be sure that some change in the foundry processes or raw materials has taken place. If the proper records are kept, it can usually be ascertained what variable factors are deviating from their normal quality level.

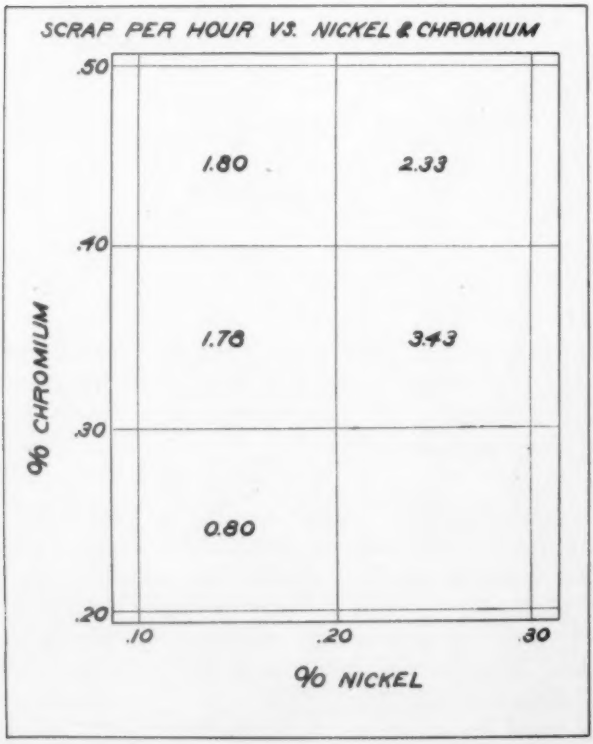


FIG. 11.

CORRELATION—TO FIND IDEAL OPERATING CHARACTERISTICS

20. Suppose that a foundry operator wishes to know the range for a measurable property which will result in the least amount of defective cylinder blocks. This value can only be determined from operating data taken from the source to which it is to be applied. Over a long period of time, this value can be obtained by practical experience. Costly trial and error methods will eventually arrive at a fairly satisfactory value. If conditions in the foundry change, the new optimum value can be determined by another costly period of trial and error. However, statistical methods will enable the foundryman to obtain the information desired more accurately in a fraction of the time.

21. Since scientific methods are used to measure sand properties, pouring temperature, chemical analysis and microstructure of iron, and carefully designed and constructed machines are used to insure that operating methods will be performed in a uniform way, surely it is high time that operating data was analyzed in a way that will bring out the most information possible.

22. Consider the graphic presentation of the relationship between Brinell hardness and the average number of scrap per hour. The choice of hardness classes conveniently fitted the data as recorded. However, for this type of graphic presentation, it is better to limit the number of classes to two or three so that the spread of the class interval is not less than one-third of the range in which it might be reasonably expected that all results could be maintained. Now when presented with information in a form similar to Fig. 3, the experienced foundryman will not accept this evidence without answers to the following questions:

(1) How do you know that this result is not due to chance alone?

(2) How can you tell that this observed relationship will remain as shown?

(3) Within what limits do you recommend that we hold Brinell hardness?

23. The probability that the observed relationship is due to chance can be calculated mathematically[21]. However, probably the most convincing proof is to show graphically that successive

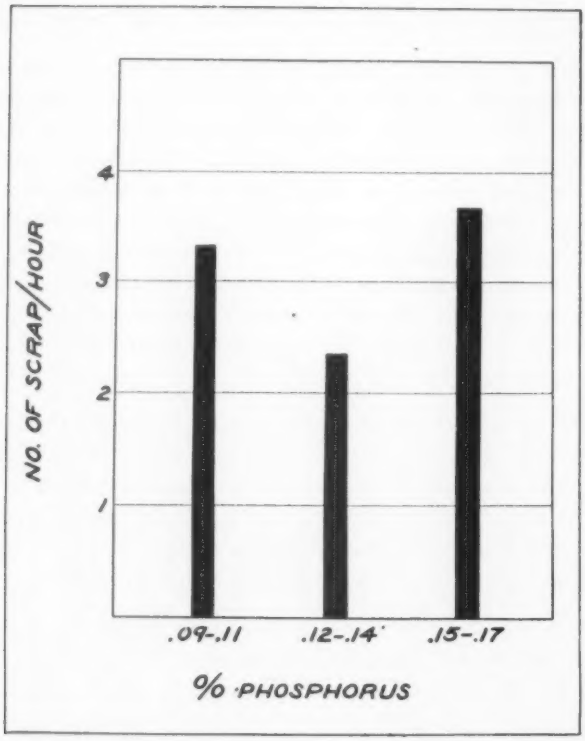


FIG. 12.

periods of time when plotted, as in Fig. 3, show the same result. In this way, according to W. Edwards Deming[22], when only two or three class intervals (instead of 5 or 10 as shown in the examples in this report) are used and short periods of time are charted the true fundamental laws governing the process are shown.

24. It is expected that the ideal range of certain properties will be subject to trends. As fines accumulate in the molding sand, a different set of properties will result in the best molding sand. Variations in available raw materials will change the ideal set of analysis and physical properties which have been set up as a standard. Therefore, it is expected that the graphic presentation method will enable the foundryman to detect these trends and so balance his process as to allow for them.

25. Figure 4 shows the manner in which hardness results were distributed for a period of one month. From this record the practical working range can be predicted.

STATISTICAL QUALITY CONTROL CHARTS

26. Statistical quality control charts are being used by an increasing number of industries. Their design and use are described in A. S. T. M. Manual on the Presentation of Data and many other publications. These charts are used to tell when a property which has been under control varies from the established quality level. Before they can be applied, the ideal operating range of each variable in the process must be determined and some degree of control established. When the average and the standard deviation of a group of data are known, and there is some indication that the distribution of the results is approximately normal, the frequency

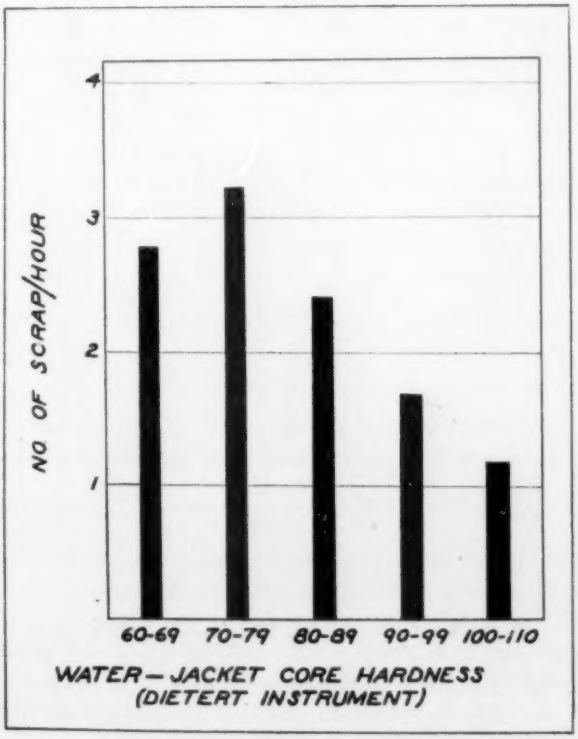


FIG. 13.

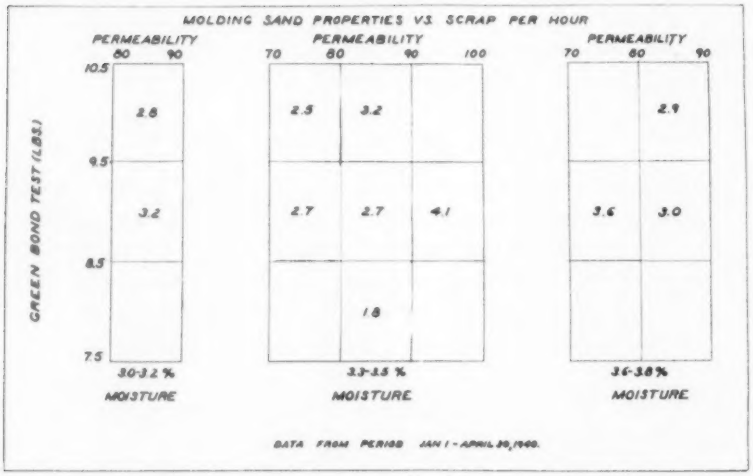


FIG. 14.

of test values at any point above or below the average can be readily determined from tables of areas under the normal probability curve in any mathematical handbook.

Example

27. Moisture tests of molding sand for the month of April were analyzed and it was found that:

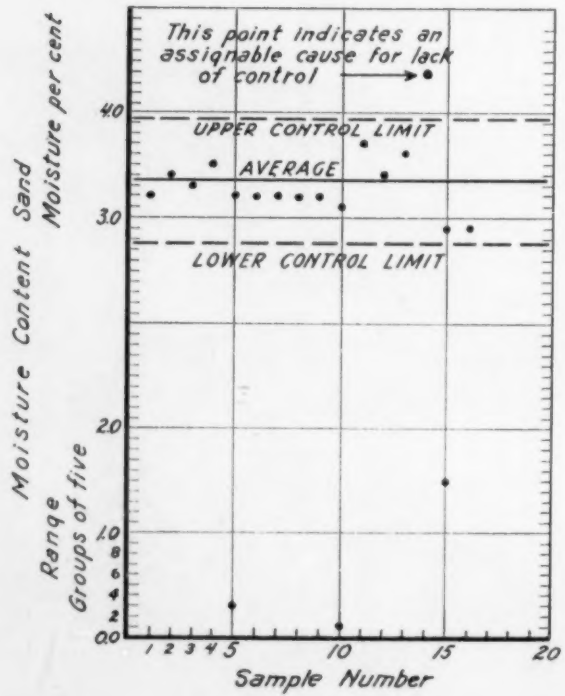
Average = 3.34 per cent
Standard deviation = 0.187 per cent.

On the first day of May a moisture test was recorded at 3.8 per cent.

Q. Has the quality level changed?

A. The frequency of results closer to the average than 3.8 per cent is 2 x area under the normal probability curve from the mean to $\frac{3.8 - 3.34}{0.187}$ standard deviations.

This value (table of areas under normal probability curve) is 0.9862 of the total area under the curve. If the quality level has not changed, then the chances are 1.4 out of 100 that this result would have occurred. Thus, each single test or group of tests may be interpreted in the light of past experience. It is easier to plot the data on a continuous chart in chronological order so that trends may be observed.



{Within these limits variation is characteristic of the process and cannot be changed without changing the process.

INSTRUCTIONS FOR USE

(1) Plot (highest-lowest) for each successive group of five.

(2) Any results falling outside of the control limit calls for *action*.

(3) Results falling inside the control limits may be considered normal.

(4) Revision of limits should be done about every 25 test results.

FIG. 15.

28. For the principles underlying the design of control charts, the reader is referred to the many recent publications on this subject (see bibliography). Figure 15 illustrates a simple case. From a previous period, average and standard deviation for moisture content of molding sand were calculated to be:

Average, 3.34 (per cent moisture).

Standard deviation, 0.19 (per cent moisture).

Control limits established were therefore: $3.34 \pm 3 \times 0.19 = 2.77$-3.94.

29. The above limits are characteristic of the process and can only be altered by changing the materials, machinery, method, or personnel. A test exceeding these limits would definitely mean that there was an "assignable cause," that is, somewhere in the process something is out of line and can be discovered and corrected. Plotting the range (highest value minus lowest value) for successive groups gives additional information for control purposes. Note, in Fig. 15, that the range for samples 11-15 inclusive is extreme compared to the two previous groups. Control limits for range are applied in the same manner as for the moisture content values.

30. When successive groups are plotted, both average and deviation can be studied. This type of record shows *when corrective action is necessary.*

31. In actual practice, it has been found very satisfactory to plot actual test values *chronologically* between high and low limit lines ($\pm$ 3 standard deviations).

Control Charts

32. The author is of the opinion that in most foundries statistical control charts can be applied only after the preliminary groundwork of determining the ideal range for each variable has been done and the variance from the established mean has been brought under control. When this work is well under way, the foundryman would do well to set up statistical control charts so that the significance of every test can be immediately interpreted on the basis of past records.

33. The charts contained in this publication were derived from operating records of a foundry making gray iron cylinder blocks. Each block had its casting date and hour cast on it. Rejections were recorded in the foundry and in the machine shop. This casting is probably one of the most intricate of the mass-produced

castings, and a very high standard is maintained by means of close inspection at several stages of its manufacture.

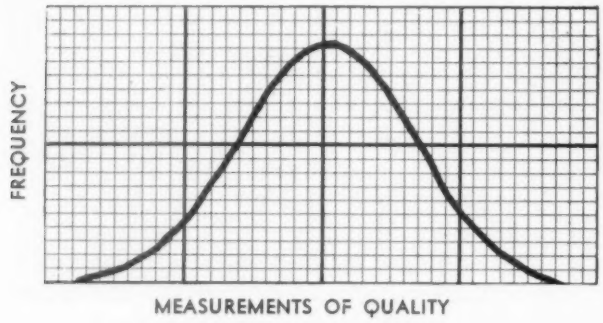
34. Operating factors were recorded on convenient forms, so that the conditions prevailing during every hour could be readily referred to. Data for drawing into charts were obtained by the simple process of plotting the number of rejects per hour against the condition existing during that hour and taking the average number of rejects per hour for each condition. For example, Fig. 3 shows that there were 2 rejected castings (average) made per hour when the Brinell hardness reading was 4.1 mm. diameter (217 Brinell Hardness No.); this was obtained by the following calculation:

$$\frac{\text{Total amount of scrap made when B.H.N. was 217-208}}{\text{Number of hours during which B.H.N. was 208-217}} = \underset{\text{Average}}{2/\text{hr.}}$$

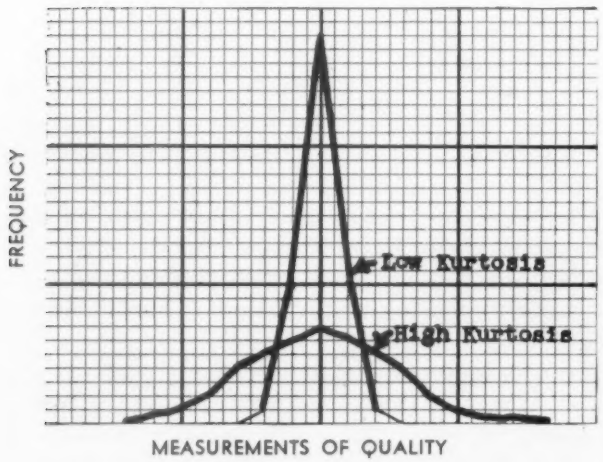
35. Successive periods of time have been plotted to see what changes, if any, take place over a time interval. As would be expected, analysis and microstructure requirements remain fairly constant but pouring temperature, molding and core sands show slight trends which are probably due to the changes which take place in the sand characteristics. The charts selected for publication are fairly representative of the conditions which existed over a period of several months.

36. The manner in which scrap occurs gives some clue as to the underlying causes. From Fig. 1, one might assume that a free system of environmental factors was operating in such a way that a coincidence of ideal properties occurred most of the time but control was not rigid enough to keep all of the factors in line; therefore, occasionally one, two, or more properties would vary from ideal.

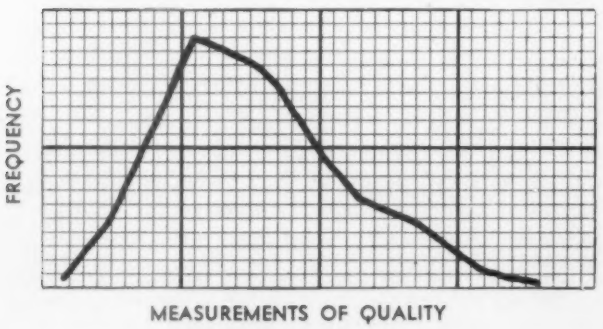
37. Fig. 2 shows that the amount of scrap increased in the later hours of the day. During the first hour the best conditions existed. The best hours were after ten o'clock rest period and after lunch. This chart leads one to many interesting assumptions but, as Schwartz and others have warned, foundrymen all too frequently draw hasty conclusions from insufficient data. Some further correlation of core properties, molding sand temperature, and mold spray conditions showed that quite a few foundry conditions varied according to the same cycle as is shown in Fig. 2. No discussion of scrap causes can entirely disregard the personal element in foundry conditions. A record of the same job with different operators will



NORMAL DISTRIBUTION—NO SKEWNESS.



DISTRIBUTION SHOWING HIGH KURTOSIS—NO SKEWNESS.



A DISTRIBUTION SHOWING SKEWNESS.

FIG. 16. DISTRIBUTION CHARACTERISTICS.

soon show that there is a great variation between individuals.

38. Fig. 3 shows a definite relationship between hardness and the occurrence of defects. Before setting up limits for future control this question must be answered:

Q. Within what limits can hardness be controlled under the present operating conditions?

A. According to past performance, as shown in Fig. 4, 95 per cent of the time Brinell hardness was within 3.9 $\pm$ 0.1 mm. It is reasonable to conclude that limits such as these could be maintained in the future even if the average was shifted to take advantage of the information in Fig. 3.

39. Figs. 5 and 6 serve to illustrate the well known fact that for each foundry its own ideal pouring temperature must be determined.

40. The relation between physical properties and castability is well defined in Fig. 7. This leads to many interesting conclusions, since micro-structure, analysis, melting and ladle addition practice are all closely connected to physical properties.

41. Fig. 8 summarizes 18,000 casts. More than a year later a one-month period gave the results of Fig. 9. Note that the trend to the axis C + Si = 5.50 per cent still persists. Note also that variations in carbon and silicon appear to have less effect upon scrap than variations in many other properties.

42. The elements sulphur, manganese, nickel, chromium, and phosphorus each have a certain desirable range, as Figs. 10, 11 and 12 demonstrate.

43. To avoid prolonging this paper, only two examples of the effect of sand properties have been included. It was found that every measurable property of sand was connected with the quality of the final casting, and that the variables of molding and core-making outweighed those of the metal in significance. Fig. 13 shows the relation between core hardness and scrap; mold hardness is even more significant. Fig. 14 shows the fallacy of maintaining a high green strength in molding sand for this particular operation.

CORRELATION OF MECHANICAL FACTORS

44. Most of the readers are probably familiar with the general practice of making a mechanical change (in pattern, gating, squeezer head, etc.) and then determining its value from an exami-

nation of from 5 to 20 samples. Since the casting quality is subject to wide variation both before and after the change was made, the few samples selected for examination are very liable to cause entirely erroneous conclusions to be drawn. However, the effect of mechanical changes can be evaluated by records kept before and after the change for a sufficient length of time. Results can be plotted as in charts, Figs. 1 to 13, or as follows:

Operating Condition	*No. of Hours*	*Casting Quality (Rejects per Hour)*
Before change	.....	....
After change	.....	.....

45. The number of test results included in each group should be enough to exclude the effect of other operating conditions. This will depend upon the uniformity of the product. Significant differences have been clearly explained by Simon[22].

CONCLUSIONS

46. Illustrations in this report were mainly confined to charts demonstrating graphically the relation between casting qualities and production variables. This phase was emphasized because it is the groundwork necessary before statistical quality control can be applied.

47. It would seem desirable to be fairly certain of the optimum ranges of each manufacturing variable before trying to control the operations but, as Schwartz and others have repeatedly pointed out, incorrect conclusions are frequently drawn from too small a sample of data and used as a basis for attempting to establish a rigid control over operating conditions. Statistical methods, by analyzing mass-produced practical research data, show the true nature of the process. Often it is more economical to proceed on empirical grounds, since the results obtained are sufficiently profitable.

48. The use of statistical methods of analysis on foundry data will bring to light the fundamental laws governing the process being examined. Many prejudices, customs and arbitrarily imposed standards will be found to be in error. When defective castings are encountered, if proper statistical records have been kept, it will be possible to see which variables have changed from their quality level, and correction can be immediately applied. In many cases, trends will be shown up so that correction can be applied before any scrap is produced.

49. Statistics do not change or improve anything, they merely provide a means of gaining information. Oftentimes the information is a clue which may easily be misinterpreted by those who are not familiar with the process of manufacture being examined. In searching for the fundamental laws underlying the production of sound castings, the metallurgist using statistical methods would uncover many relationships not even suspected by the practical foundryman.

50. This article has attempted to show in a very simple way what information may be obtained from operating records. The foundry operator will find that the time spent in a careful analysis of his operating data will be repaid many times over by a more thorough knowledge of the process. Too often foremen and foundry executives spend most of their time correcting bad conditions which would never have arisen if the fundamental principles of the process were known and statistical control were in effect.

51. At least as much consideration should be given to industrial research using statistics as is given to laboratory research.

ACKNOWLEDGMENT

52. The author wishes to express his thanks to N. C. MacPhee[23], under whose supervision much of the material was obtained, and to Major L. E. Simon[24] for his advice on statistical methods. The staff of the metallurgical laboratories, under Dr. G. S. Farnham, has cooperated in the preparation of this paper. The encouragement and support of C. S. Parsons[25] in this project are deeply appreciated.

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[22] Bureau of the Census, U. S. A.

[23] Metallurgist, Bureau of Mines, Department of Mines, and Resources, Ottawa, Canada.

[24] Ordnance Department, U. S. Army.

[25] Chief of the Metallic Minerals Division of the Bureau of Mines, Ottawa, Canada.

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DISCUSSION

Presiding: A. E. SCHUH, U. S. Pipe & Foundry Co., Burlington, N. J.

CHAIRMAN SCHUH: We should be grateful to Mr. Fairfield for pointing out a concrete application of statistical principles for assistance in production control. Many foundries, by their nature, will not lend themselves readily to such analysis, but, on the other hand, many more foundries than we realize do have work of such nature that statistical analysis of the causes for variation in it would be extremely useful. I understand ballistics experts of the Ordnance Department who have been using this method very extensively have gone over this paper and commented very favorably on it.

MEMBER: I believe that we should congratulate the authors on a very nice study of the things that happen in the foundry, the very convenient form in which they are put for reference and the method of attack used. We have used the control chart method in our foundries for a good many years. However, we have not sold our own organization fully on its benefits.

The most convenient way that we have found in the few important cases that we really do keep up is the card system. We take 3- x 5-in. cards, run them through the mimeograph, write in the important details of the problem we are studying, and have somebody fill them out as the reports come in. Of course, a sorting machine which would sort the cards into groups automatically would be a wonderful time saver, but we do not have enough statistical work to justify such a machine, or at least we have always thought we did not have. We find, at the end of a period such as six months, that it is possible to sit down and study any one variable simply by the size of the pile of cards.

F. G. SEFING[1]: I would like to point out something rather interesting here because in our work we are often confronted with the problem of making castings such as cylinders and cylinder heads.

Supposing we were to go into a shop that knew nothing about making cylinders or cylinder heads. We would suggest 3.25 per cent carbon iron for the job. So often the foundryman does not realize how important it is to stay close to 3.25 per cent carbon iron. It is all right with him if it is 3.40 or 3.10 per cent carbon. Statistical data will show trouble as soon as he gets off the prescribed recommended compositions or recommended practices with respect to pouring or melting temperatures, or the kind of coke used, etc.

That is a little different from the viewpoint of keeping records of what has happened and then going back and adjusting the practice to the results obtained in the last 6 months.

Figure 8, for example, shows the relationship between scrap losses and the carbon-silicon content on cylinder blocks. A diagonal can be run on the diagram which shows the least amount of scrap, and this diagonal coincides with the diagonal of a balanced iron of the Maurer diagram.

CHAIRMAN SCHUH: These remarks are borne out by some of our ex-

[1] International Nickel Co., New York, N. Y.

periences. We went to this method of trying to keep track of things going on and to associate various variables to get a better class of relationships more or less in self-defense from the research standpoint, which meant going over very numerous inspection and rejection reports, on the basis of which graphs of various kinds were drawn up. In doing that, we thought we might as well run copies off for the benefit of the operating department. Every month that we sent out a new set of these graphs, we would ask for comments on the part of the operating people, and all we would get in return was, "Very interesting—but how do you use them?" We are going to study this particular application as it was presented and try our methods somewhat differently with the hopes of obtaining a better understanding throughout the management of the company of the importance of this method of approach, because it really does mean money.

MEMBER: When we get the statistical conception of a frequency curve, we find that we can show the management a frequency curve. It is quite easy to show that we cannot have one without a couple of tails on it, so that they will quit expecting the impossible, having a block of results right square in the middle of where they want them.

MR. FAIRFIELD: That statement is very true. The U. S. Ordnance is beginning to consider products in the light of the frequency distribution principle. Extreme results, or "tails," are a normal occurrence characteristic of most processes. They occur in spite of arbitrary specifications. Statistical quality control methods are being used to tell when an extreme result is normal (indicating the process is operating as usual) and when it is due to a definite removable cause.

The purpose of this paper was solely to direct attention to a phase of foundry operation which is the most uncertain, subject to prejudice and the frailty of human judgment. The collection of data is characterized by precision of action and sources of error are rigorously suppressed. In the interpretation of collected data, however, there is no pattern of behavior to follow and mistaken theories are developed.

Statistical methods take large quantities of data and condense them into a concise form. This makes the problem of interpretation much easier. For descriptions of statistical methods the reader is referred to the bibliography attached to this paper.

A Study of the Flowability of Foundry Sands

By Erik O. Lissell and Eugene J. Ash*, Ann Arbor, Mich.

Abstract

Flowability is an important property of foundry sands, but in the past has been rather difficult to determine. Several investigations of this property have been made and in a recent meeting of the Subcommittee on Flowability of the Foundry Sand Research Committee, the decision was reached that the term flowability involved several factors. In this paper, the authors examine that property of molding sand known as flowability from two different angles, and by their efforts, contribute to a better understanding of exactly what the term means. The authors differentiate between true flowability and compression flow. In their investigations, they have used both the round-grained and angular-grained silica sand and various types of binders and reached the conclusion that while there are several methods for determining the compression flow of sand, no method has as yet been developed for the determination of true flowability as they interpret the term.

1. A study of the literature on the subject of flowability of foundry sands indicates that there is a considerable difference of opinion as to the nature of this property. The main reason for this seems to be that the term flowability, when applied to sands, embraces not one but several characteristics of the sand.

2. The flowability of molding sands has been defined as "the property which enables the sand to flow when ramming pressure is applied." Dietert and Valtier[1] made this somewhat vague definition more concise by the following additional statement: "The greater the ease of flowing the more readily will the various sand grains, comprising a mold, flow together until all sand grains are

*Instructor and former Associate Professor, respectively, Department of Metal Processing, University of Michigan.

[1] Superior numbers refer to bibliography at end of paper.

Note: This paper was presented at a Sand Research Session of the 46th Annual A.F.A. Convention, Cleveland, O., April 24, 1942.

in contact, . . .'' This clarification suggests that Dietert and Valtier look upon flowability as the ease with which sand can be compressed. Their method of determining flowability, *i.e.*, as the decrease in height of a partially rammed specimen under a standard blow, is a further indication of this.

3. Kyle[2] is studying the same property, namely, compressibility, but from the standpoint of obtaining a uniform structure. Aware of the progressive nature of the compression of foundry sands, he determines the variation in surface hardness at various distances from the point where pressure has been applied. Since surface hardness of a given sand is proportional to density or degree of compression of the sand, the test is actually a compressibility determination.

4. Appreciating the fact that the term ''flowability'' stands for a combination of properties rather than a definite one, the writers have made an attempt to break up this complex property in its main components. The main part of this investigation is limited to only one phase of flowability called compression flow.

Flowability

5. It might be helpful to keep the difference between liquids and plastic solids in mind when considering flowability. A solid foreign body, partially immersed in a liquid, will readily displace the liquid. Removal of the body will immediately restore the original conditions, provided the liquid is normal and not supercooled. If the same foreign body is forced into a plastic solid, the solid will deform slightly, and the deformation is more or less permanent. Furthermore, a liquid will fill all cavities under the influence of the gravitational force when poured into an intricate container.

6. The grains of a hypothetical sand, under certain conditions, may act similarly to the molecules of a liquid. Under other circumstances, they are merely the constituents of a solid. Figure 1 shows these two cases. The two sands are made up of sand grains that are assumed to be completely round and of the same size. Furthermore, the grains are shown in open packing to make the figures less intricate.

Ideal Sand, Showing Complete Flowability and No Compressibility (Fig. 1A)

7. The sand grains, all in contact, are surrounded by a thin film of an ideal lubricant, completely eliminating friction. The grains

will automatically arrange themselves in closest possible packing under influence of the gravitational force. A rod pushed down into the sand will displace the grains very easily, forcing them out into the space between rod and container. The individual grains move exclusively in directions other than that of the force applied on the rod.

Ideal Sand, Showing Compression Flow or Compressibility But No True Flowability (Fig. 1B)

8. The sand grains, in this case, are separated by a strong binder

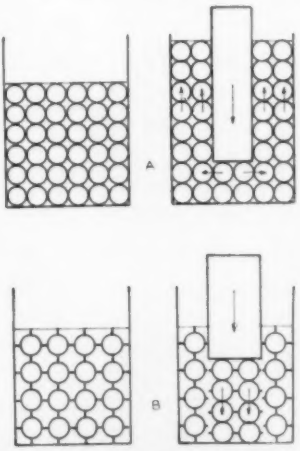


FIG. 1—IDEAL SANDS INDICATING THE DIFFERENCE BETWEEN TRUE FLOWABILITY AND COMPRESSION FLOW.

of a high plasticity. It is assumed that it is possible by means of riddling to arrange the grains symmetrically according to the figures. A rod forced down into this sand will compress the sand locally as illustrated by Fig. 1B. Due to the high strength of the binder coating the grains, the intergranular friction between the grains in contact will be very high, restricting the movement of the grains in all directions, except that of the compressing force.

9. In the true sense of the word, sand *B*, Fig. 1, has no flowability, while sand *A*, Fig. 1, shows a complete flowability. A flow takes place in sand *B*, but it is a flow of the binder between the sand grains within the region of direct compressive action and a movement of these grains with respect to each other to a state of contact or close packing.

10. A sand showing complete flowability will, when put into a

mold or core box, completely surround the pattern and fill all cavities even without ramming. The density of this sand will be uniform throughout, and ramming pressure will be conducted in all directions. A sand of the other type, lacking true flowability, has to be tucked into all cavities, and the ramming force has to be applied as closely as possible and at right angles against the pattern surface at all points.

Actual Foundry Sands

11. The grains in actual molding and core sands are, however, neither uniform in size, shape, and distribution, nor is there an absence of friction between them. Foundry sands, therefore, show properties which are a combination of the extreme ones just discussed.

12. In any foundry sand, distinction has to be made between the following types of flow:

1. Flow under the influence of the gravitational force. This is solely a movement in the surface layers of the sand when filled into a mold. The angle of repose will give an indication of this property which could be called *autoflowability*.

2. Flow under influence of applied force, *e.g.*, ramming or squeezing.

(a) Flow of the grains in the direction of the applied force. This property could be called compression flow, or simply compressibility. Any compression test is suitable to determine this property.

(b) Flow of the grains in directions other than that of the applied force. This is the true flowability of the sand. An extrusion test to determine the true flowability will be described in this paper.

13. A dry sand free from binder, or a sand containing linseed oil, will show a high degree of autoflowability. This causes a green linseed-oil core to sag badly if not properly supported.

14. Oil-bonded sand also possesses considerable true flowability. If rammed in a concave core box of cylindrical shape, the sand will tend to be thrown out of the box. A sand of high green strength, *e.g.*, cereal-bonded sand, on the other hand will stay in the box and compression occurs at the point of the blow.

15. The true flowability of foundry sands can be greatly increased if air cushions are introduced between the grains. This decreases the intergranular friction more or less completely, air

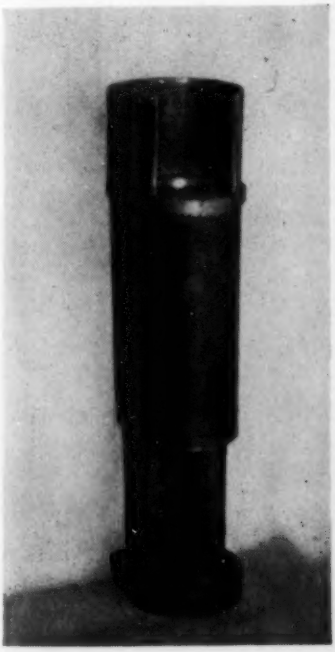
actually being the medium in which the grains move. This fact has been utilized practically in the core-blowing process.

16. The purpose of this investigation was mainly to study the work necessary to compress different sand mixtures and in this way obtain a measure of the compression flow or compressibility of the mixtures. A set of experiments was also run on extrusion of similar mixtures as an indication of their true flowability.

Sands Used

17. The base sands used for the tests were (1) Ottawa, round-grained silica sand, A.F.A. Fineness 40, and (2) an angular-grained silica sand with an A.F.A. Fineness 36. The sands were cleaned and graded further by sieving.

18. The test sands, bonded with Western bentonite, were mixed in a wing mixer and cured in sealed jars for 24 hours. The linseed-oil mixtures were made immediately before testing.



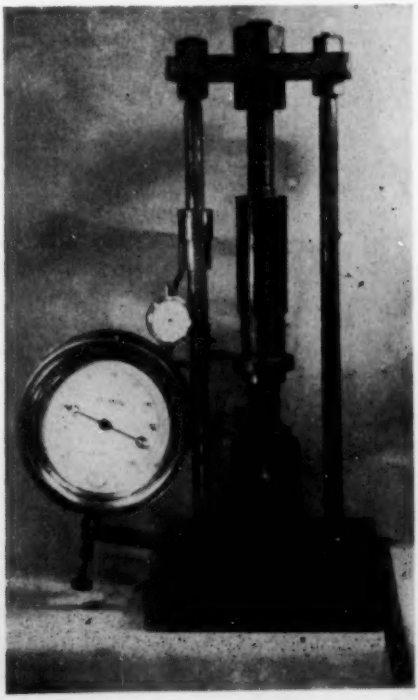


FIG. 2—LEFT—CONTAINER AND ORIFICE FOR EXTRUSION TESTS. FIG. 3—RIGHT—COMPRESSION APPARATUS WITH GAUGE, VERNIER, AND INDICATOR DIAL.

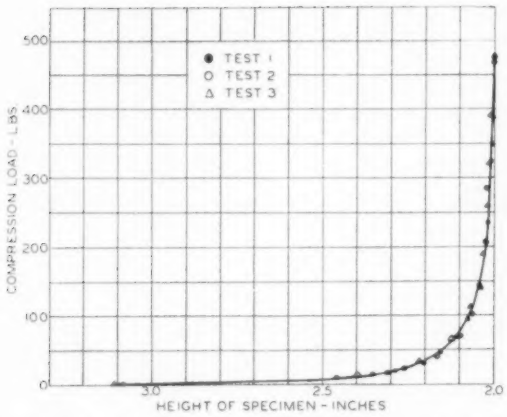


FIG. 4—COMPRESSION DATA OBTAINED ON THE COMPRESSION APPARATUS FOR THREE TESTS ON THE SAME SAND.

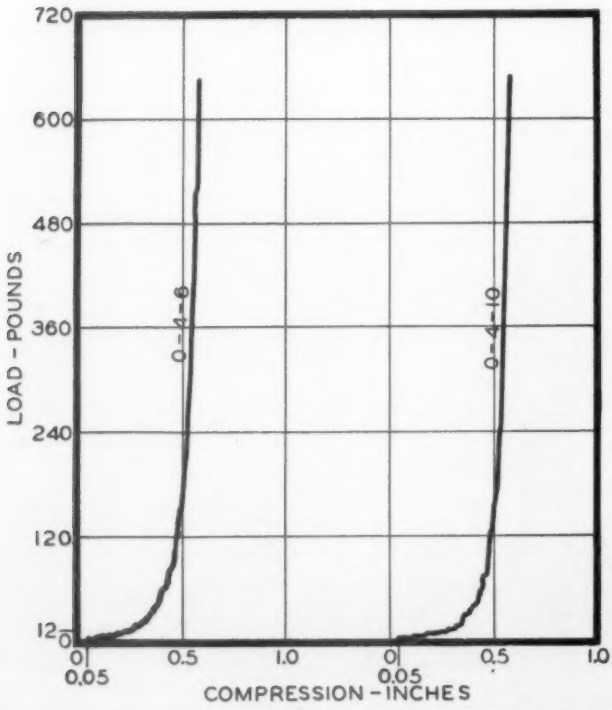


FIG. 5—COMPRESSION CURVES OBTAINED IN A REGISTERING UNIVERSAL TESTING MACHINE.

EQUIPMENT AND EXPERIMENTAL PROCEDURE

Extrusion Tests

19. The apparatus used for the extrusion tests is shown in Fig. 2. The sand is simply enclosed in a regular A.F.A. specimen container and extruded through the 1-in. hole in the cover. A stripping post serves as piston. The compression was done in a universal testing machine.

Compression Tests

20. Compression of the test specimens was done in an A.F.A. standard specimen container. The sand was well disintegrated before it was poured into the container, and care was taken to obtain as even a distribution as possible.

21. The bulk of the tests was made on the compression machine shown in Fig. 3. The pressure was generally applied in steps of 5 lb. in the range 0 to 50 lb., 10 lb. in the range 50 to 100 lb., and 75 lb. in the range 100 to 475 lb., which was maximum pressure. The degree of compression was read on the Vernier scale and the dial indicator. Three sets of data were taken for each sand mixture. Figure 4 indicates the spread of values on a normal set of tests.

22. Some of the compression tests were run on a recording universal testing machine. The rate of loading was in this case 0.1 in. per min. in the range 0 to 200 lb., 0.05 in. per min. in the range 200 to 400 lb., and 0.01 in. per min. in the range 400 to 600 lb. Figure 5 shows the type of curves obtained. It has to be pointed out that these curves do not include compression caused by the loose plunger which was put on top of the specimen before the actual test began. The plunger weighs 3 lb.

RESULTS OBTAINED

Extrusion Tests

23. The extrusion tests are recorded graphically in Fig. 6. Total load is plotted against time. The rate of loading was 0.03 ft. per min. The sand in the tube is compressed progressively under increasing load until a constant extrusion pressure is reached. The time necessary to attain this constant pressure is largely a function of the compressibility of the sand while the extrusion pressure determines the true flowability. A high true flowability results in a low extrusion pressure. The dry sand has a relatively high inter-

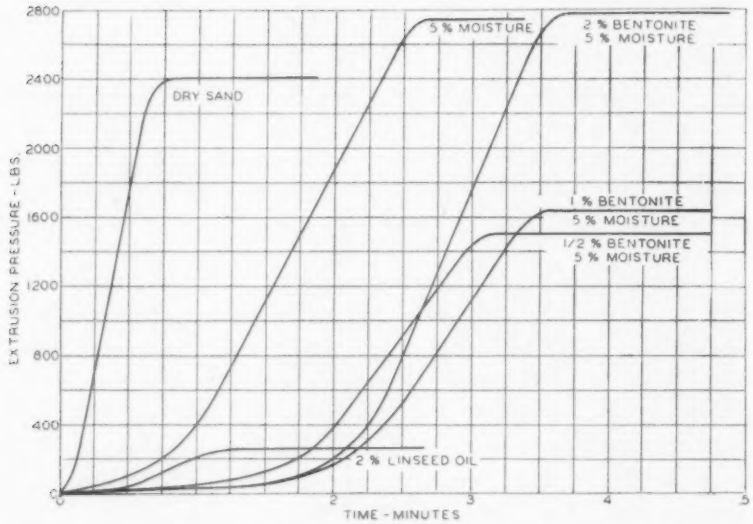


FIG. 6—EXTRUSION CURVES FOR ROUND-GRAINED SILICA SAND AND VARIOUS BINDERS.

granular friction and therefore flows less easily than a sand bonded with linseed oil or a diluted bentonite mixture where the binder acts as a lubricant. Water alone increases the friction between the grains and consequently increases the true flowability. This result is in agreement with earlier findings by the authors[3]. The flowing pressure increases rapidly with the increasing strength of the binder. Experiments conducted on a mixture of 6 per cent bentonite and 5 per cent water resulted in breaking of the orifice at a load of 26,000 lb.

Compression Tests

24. A number of compression tests were run by varying the nature or the amount of one of the constituents of the sand at a time.

25. *Effect of Variations in Bentonite Content.* In the case of sand mixtures with varying bentonite content, the weight of the sand in the compression tube was kept constant. It was slightly changed only if the final height of the specimen fell outside the limits 2 in., ± 0.05 in. Table 1 gives the sand composition, weight, initial height, and final height of the specimen. It should be pointed out that the volume weight or density of the final specimens is almost independent of bentonite content within the limits tested.

26. Assuming that a slight variation in the final height of the compressed specimen would not materially influence the compression data, all load and compression values were recalculated to a final height of 2.0 in.

27. The hyperbolic compression curves, Figs. 7 and 8, show compression load plotted against height of the specimen. The area under the curves represents the compression work. The compression work, calculated from these curves, is given in Figs. 9 and 10 as a function of height of the specimen. Especially at high bentonite contents, the shape of these two types of diagrams indicates that most of the compression takes place before the pressure applied has reached 25 lb. The force necessary for compression increases very rapidly towards the end of the test. The same is true for the work input. The results indicate that, to obtain a given density, more work has to be put in as the bentonite content increases, other factors being constant. This is in accordance with the practical experience in the foundry. A sand of high green strength is harder to ram than one of low green strength. A sand mixture containing 10 per cent bentonite attains its maximum

Table 1

DATA ON COMPRESSION TESTS

Sand	*Bentonite, per cent*	*Moisture, per cent*	*Weight, grams*	*Initial Height, in.*	*Final Height, in.*	*Total Compression Work, ft. lb.*
Round-grained Silica	0	5.0	167	2.50	2.01	1.63
	2	4.5	167	3.25	2.03	2.58
	4	4.8	167	3.50	2.02	3.34
	6	4.9	167	3.75	2.01	4.25
	8	5.0	167	4.00	1.97	5.76
	10	5.2	167	over 4.00	1.95	6.20
Round-grained Silica 40-mesh	0	5.0	168	2.50	2.00	1.44
	2	4.5	167	3.10	2.02	2.50
	4	4.6	167	3.30	2.01	2.88
	6	4.7	167	3.60	2.01	3.67
	8	4.7	167.5	3.75	2.00	4.72
	10	5.0	168	4.00	1.97	5.42
Round-grained Silica, 70-mesh	2	4.7	166.5	3.25	2.04	2.60
	6	4.6	166.5	3.65	2.04	4.08
Angular-grained Silica, 40-mesh	0	5.0	146	2.60	2.05	3.02
	2	4.7	146	3.25	2.06	3.97
	6	4.6	146	3.50	2.05	4.70
	10	4.8	146.5	3.75	2.00	6.25

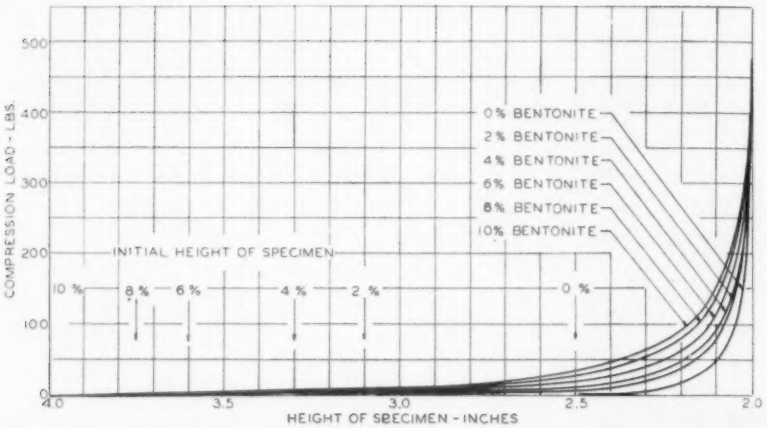


FIG. 7—COMPRESSION CURVES FOR 40-MESH ROUND-GRAINED SILICA SAND BONDED WITH VARIOUS AMOUNTS OF BENTONITE, MAINTAINING THE MOISTURE CONTENT AT 5 PER CENT.

strength at 5 per cent moisture. If the bentonite is lowered to 2 per cent, the sand will be overtempered and the strength consequently will be lower, as has been shown by Briggs and Morey[4]. This explains the increase in compression strength with increasing bentonite in the mixtures.

28. Since the compression flowability test is somewhat related to the Dietert flowability test, it is worth while to compare the results obtained by the different methods. In Figs. 11, 12 and 13, the total compression in inches, the inverse value of the Dietert flow-

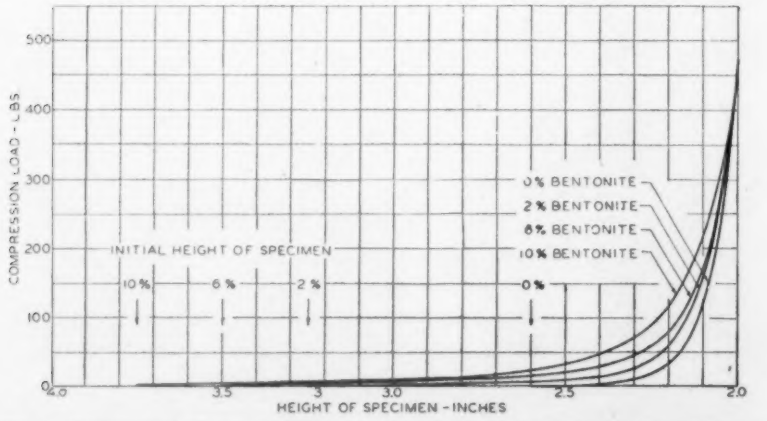


FIG. 8—COMPRESSION CURVES FOR 40-MESH CRUSHED SILICA SAND BONDED WITH VARIOUS AMOUNTS OF BENTONITE, MAINTAINING THE MOISTURE CONTENT AT 5 PER CENT.

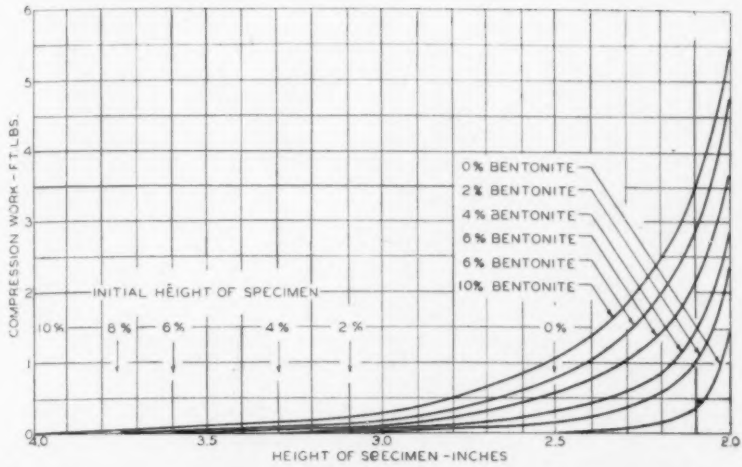


FIG. 9—COMPRESSION WORK CURVES FOR 40-MESH ROUND-GRAINED SILICA SAND BONDED WITH VARIOUS AMOUNTS OF BENTONITE, MAINTAINING THE MOISTURE CONTENT AT 5 PER CENT.

ability, and the total compression work are plotted versus percentage of bentonite. The compression work and the Dietert flowability check very closely in every respect. The degree of compression shows

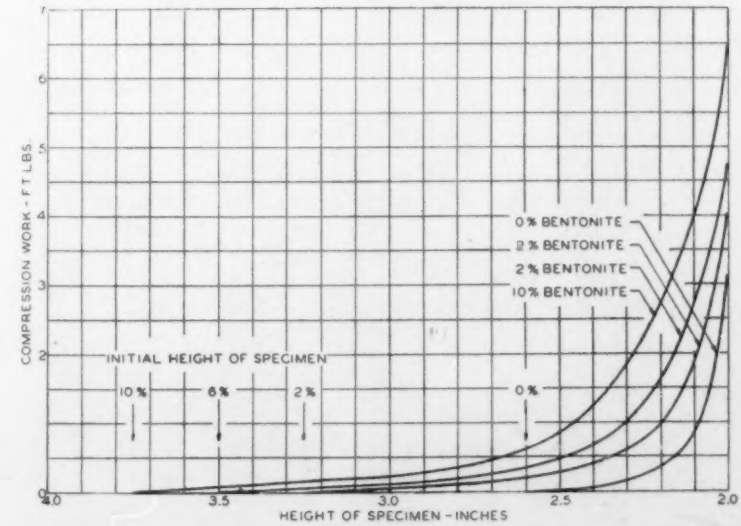


FIG. 10—COMPRESSION WORK CURVES FOR 40-MESH CRUSHED SILICA SAND BONDED WITH VARIOUS AMOUNTS OF BENTONITE, MAINTAINING THE MOISTURE CONTENT AT 5 PER CENT.

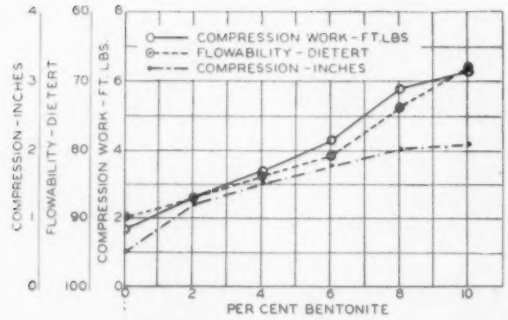


FIG. 11—TOTAL COMPRESSION, DIETERT FLOWABILITY, AND TOTAL COMPRESSION WORK AS A FUNCTION OF BENTONITE CONTENT FOR ROUND-GRAINED SILICA SAND, MAINTAINING THE MOISTURE CONTENT AT 5 PER CENT.

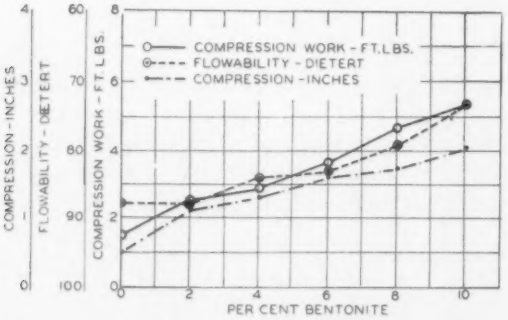


FIG. 12—TOTAL COMPRESSION, DIETERT FLOWABILITY, AND TOTAL COMPRESSION WORK AS A FUNCTION OF BENTONITE CONTENT FOR 40-MESH ROUND-GRAINED SILICA SAND, MAINTAINING THE MOISTURE CONTENT AT 5 PER CENT.

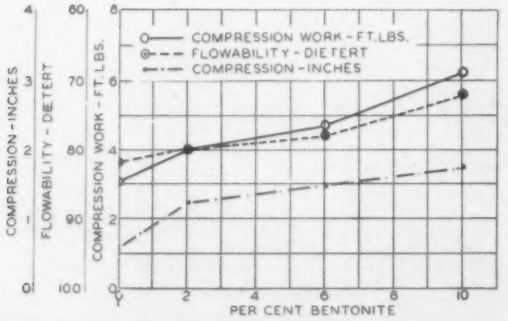


FIG. 13—TOTAL COMPRESSION, DIETERT FLOWABILITY, AND TOTAL COMPRESSION WORK AS A FUNCTION OF BENTONITE CONTENT FOR 40-MESH CRUSHED SILICA SAND, MAINTAINING THE MOISTURE CONTENT AT 5 PER CENT.

Table 2

DATA ON WATER AND OIL MIXTURES

Sand	*Oil, per cent*	*Moisture, per cent*	*Weight, grams*	*Initial Height, in.*	*Final Height, in.*	*Total Compression Work, ft. lb.*
Round-grained Silica	0	5	167	2.50	2.01	1.63
	2	0	163.5	2.06	2.00	0.63
	2	5	171	2.13	1.96	

the same general trend as the other two, but the magnitude of the values seems to vary differently.

29. *Effect of Linseed Oil.* The data for the oil and water mixtures are given in Table 2.

30. Oil lubricates the sand grains and therefore makes it possible to obtain a close packing without external pressure. Water, on the other hand, increases the intergranular friction and tries to maintain a more open packing, making a certain degree of compression possible. In the compression and compression work curves, Figs. 14 and 15, this is evident from the difference in total compression and the compression work at any stage. The curves for mixtures 2 and 3, Table 2, practically overlap each other.

31. *Effect of Variation of Moisture in Bentonite Mixtures.* The specimen weights chosen in the experiments with different moisture contents were based on a constant dry volume weight or density of the final specimen equal to 160 grams. The mixtures and the test data are given in Table 3.

32. The curves, Figs. 16, 17 and 18, indicate that the compressibility of the sand decreases with increasing moisture content, suggesting that 2 per cent moisture in the mixture corresponds to

Table 3

DATA ON EFFECT OF VARIATION OF MOISTURE IN BENTONITE MIXTURES

Sand	*Bentonite, per cent*	*Moisture, per cent*	*Weight, grams*	*Initial Height, in.*	*Final Height, in.*	*Total Compression Work, ft. lb.*
Round-grained Silica	4	2	163.5	3.80	2.05	3.76
	4	4	166.5	3.70	2.03	3.51
	4	6	170	3.70	2.05	3.24
	4	10	176	3.40	2.05	2.47

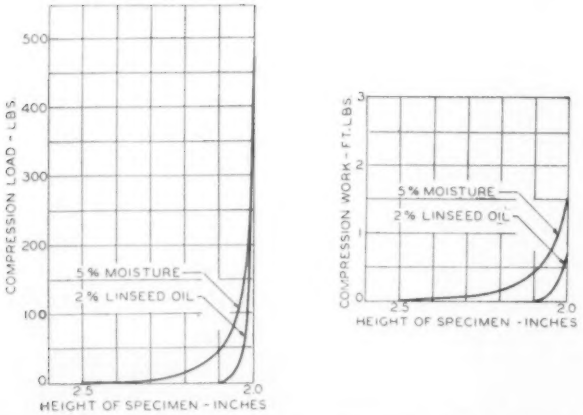


FIG. 14—LEFT—COMPRESSION CURVES FOR ROUND-GRAINED SILICA SAND MIXED WITH LINSEED OIL AND WATER. FIG. 15—RIGHT—COMPRESSION WORK CURVES FOR ROUND-GRAINED SILICA SAND MIXED WITH LINSEED OIL AND WATER.

or approaches the point of maximum strength of the binder. Increasing moisture content makes the bentonite weaker from this point on. The initial height of the specimen is lowered because the grains are no longer as widely separated as before. Compression load and work are decreased due to increased flowability of the binder.

33. *Effect of Variation in Size and Shape of Sand Grains.* The

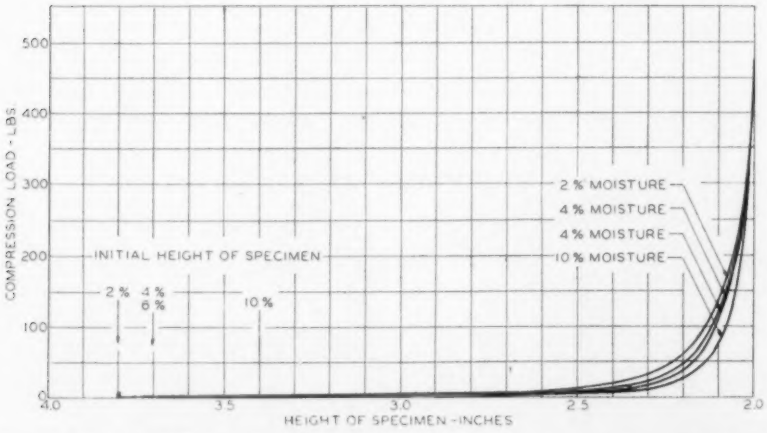


FIG. 16—EFFECT OF MOISTURE ON THE COMPRESSION CURVES OF ROUND-GRAINED SILICA SAND CONTAINING 4 PER CENT BENTONITE.

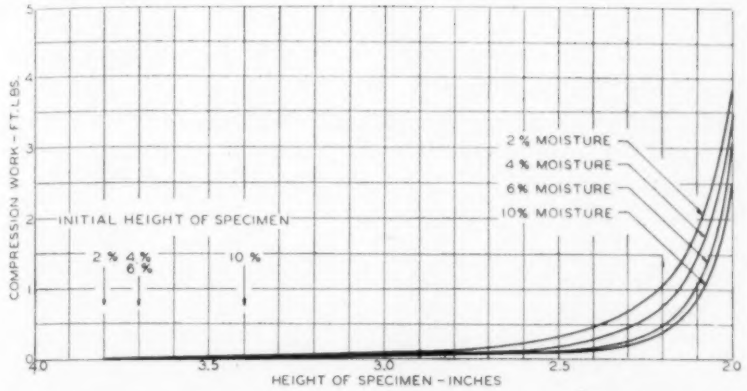


FIG. 17—EFFECT OF MOISTURE ON THE COMPRESSION WORK CURVES OF ROUND-GRAINED SILICA SAND CONTAINING 4 PER CENT BENTONITE.

compression load and compression work curves for 40- and 70-mesh round-grained silica sand and 40-mesh angular-grained sand mixed with 6 per cent bentonite and approximately 5 per cent water are shown in Figs. 19 and 20. More work is obviously required to compress the angular sand than the round due to higher friction between the sharp grains which restricts movement not only of the grains themselves but also of the binder between them. It also could be expected that the finer grains should be harder to compress in view of the larger amount of surface exposed and the decrease in size of the intergranular voids. Both of these factors will restrict the free flow of the bentonite which is essential for a high compressibility value.

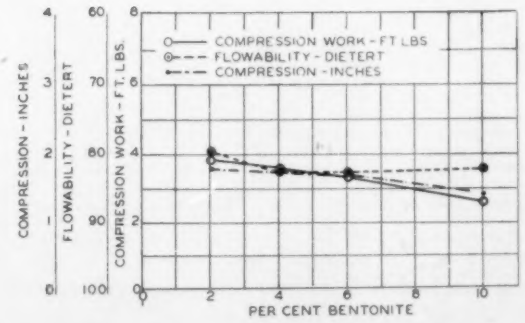


FIG. 18—TOTAL COMPRESSION, DIETERT FLOWABILITY, AND TOTAL COMPRESSION WORK AS A FUNCTION OF MOISTURE CONTENT FOR ROUND-GRAINED SILICA SAND, BONDED WITH 4 PER CENT BENTONITE.

CONCLUSIONS AND RECOMMENDATIONS

34. From the results of this investigation, the following recommendations and conclusions may be drawn:

1. Distinction should be made between flowability under conditions of freedom from any external force other than the gravitational, which could be called autoflowability, and the flow of a sand under an applied force.

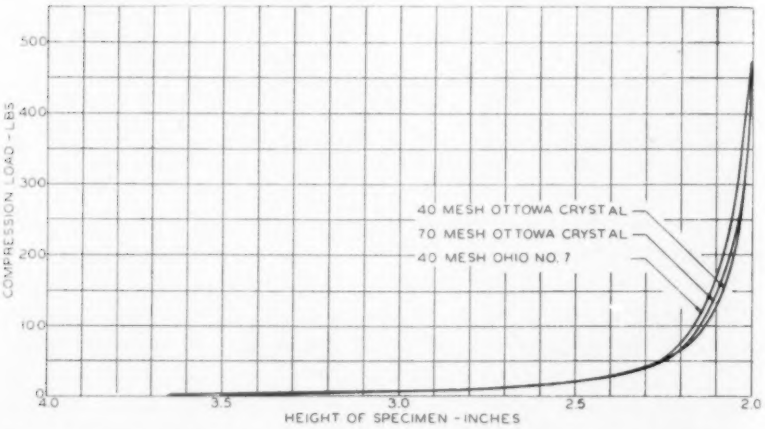


FIG. 19—EFFECT OF SIZE AND SHAPE OF GRAINS ON THE COMPRESSION CURVES OF VARIOUS SANDS, BONDED WITH 6 PER CENT BENTONITE AND 5 PER CENT WATER.

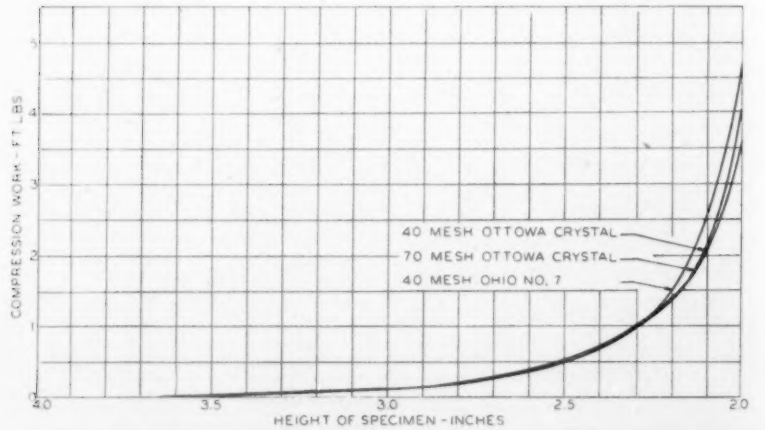


FIG. 20—EFFECT OF SIZE AND SHAPE OF THE GRAINS ON THE COMPRESSION WORK CURVES OF VARIOUS SANDS, BONDED WITH 6 PER CENT BENTONITE AND 5 PER CENT WATER.

2. The flowability of a sand under an external force, such as ramming, squeezing, jolting, and also the pressure of molten metal can be divided into:

(a) Compression flow, which is mainly a flow of the binder between the sand grains and the movement of the grains themselves largely in the direction of the applied force.

(b) True flowability, which is the flow of the sand grains in directions other than that of the applied force.

3. Several good testing methods have been devised to determine the compression flow. The Dietert method shows an excellent agreement with flowability in terms of total compression work as described in this paper, and is recommended as a good standard test on compression flow.

4. No method is developed for the determination of the true flowability. The extrusion method has here been suggested as one possible approach to the problem, and further work along this line might prove fruitful.

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DISCUSSION

Presiding: N. J. DUNBECK, Eastern Clay Products Co., Eifort, Ohio.
Co-Chairman: C. M. SAEGER, JR., Bureau of Standards, Washington, D. C.

CHAIRMAN DUNBECK: This work on flowability is very interesting, and something that probably most of us think we have not known quite enough about so far. I think we have rather a new slant on it in this paper, and I hope more work can be done on it. In mentioning that the round-grained sand and the angular-grained sand had different flowability, was that a difference of some real magnitude? Was it something that you could just measure, or was it a really great difference?

MR. LISSELL: Comparing the sands shown in Fig. 19, the round-grained 40-mesh sand showed a flowability, or a compression work, of 3.67 ft.-lb. The angular silica, 40-mesh, showed a flowability of 4.70 ft.-lb., a difference which is appreciable. It is to be noted in this case, however, that the weight of these two specimens is not the same.

E. PRAGOFF, JR.[1]: I was interested in the curve showing pressure-time relationship, using the extrusion instrument. Will you give us a little bit more about that, that is, in terms of the units and relationship of one to the other?

MR. LISSELL: Figure 2 shows the apparatus. The piston moves upward, and because the area at the top of the tube is restricted as compared with the area of the tube, the grain has to move over toward the small top opening before it can flow through it. The movement of the grain must be in the direction other than that in which the force is applied. It is not merely compression. However, the sand must be partly compressed before the sand flow actually reaches a constant volume. Sand will be coming out of the small top hole during the entire test, from the beginning of the compression, but, in time, a steady flow is reached. In plotting those curves, I simply plotted the force on the container versus the time.

MR. PRAGOFF: The total time the force was applied?

MR. LISSELL: Yes. We recorded at certain intervals.

RUSSELL MANLEY[2]: Do I understand that you took a specimen, rammed it, and then put it in that tube?

MR. LISSELL: No, it cannot be rammed first. Care must be exercised in putting the sand in the tube. If the sand is rammed just a little or is pressed down before extruding is started, a different shaped curve will be the result.

MR. MANLEY: That is what I wondered about. We started to do some similar work. At the time, we did not have anything that enabled us to make our own heap sands, and we soon came to the conclusion that flowability on new molding sand really did not mean a lot, for our answers varied so tremendously on the same sand the way it was worked up. If a good, high flowability, or, shall we say, moldability was desired, the sand had to be in the most fluffy state possible. If we took the sand and shook it a little bit and put in the specimen, we got one answer. If we took the sand and worked it a little bit and got it in just the right degree of fluffiness, the flowability would go way up. In those flowability tests, we used a washer ½-in. thick, with a hole in the center, tapering from ¾-in. at the top to ½-in. at the bottom. This washer fits into the bottom of a standard specimen tube. We found immediately that the condition of the sand changed the flowability. We rammed our specimen once, twice, and three times, and compared the hardness right at the end of the little tip down at the end, with the hardness on the shoulder at the top of the washer to find out if the sand is going to fill pockets and give a good hard mold surface when rammed. I have seen cases where sands containing too much bentonite flowed out from under

[1] Hercules Powder Co., Wilmington, Del.
[2] Manley Sand Co., Rockton, Ill.

the rammer. That is an extreme case of flowability. In making large molds, sands with high flowability are undesirable.

MR. LISSELL: Our experience has been much the same. As soon as a high compressibility is reached, the friction between the grains becomes very high, and there will be no elastic flow to speak about at all. Therefore, it is impossible to get any result in a test like that. It is actually an indication of that elastic flow as almost negative in this case.

MR. MANLEY: Do you cover the hole, fill the tube and then invert it over the compression post?

MR. LISSELL: No, we used a holder to keep the tube as high as possible, riddled the sand down to get it as fluffy as possible, and then put the top on. There is no load on the sand to start with. If the specimen is compressed so the grains get in the closest possible contact, there seems to be very little possibility of moving them with respect to each other in directions other than that of the applied force, and, therefore, there is no sand extrusion.

MR. MANLEY: We found in what we did that we had to either jolt the sand or use a vibrator on it for a definite period, and we established a semi-standard of dropping the sand container and all just exactly one-in., three times. Until we did that, we had absolutely no answer at all, and we could not check anything.

MR. LISSELL: On the other hand, if you take linseed oil and mix it in the sand, it can be rammed as hard as desired. Then, if it is put in the extrusion apparatus, under the machine, and compressed, the sand will come out very nicely, because there is no high friction between the grains.

CO-CHAIRMAN SAEGER: Assume that it is a 1-in. hole, as you say, is it a straight wall hole?

MR. LISSELL: Yes.

CO-CHAIRMAN SAEGER: Did you try any taper hole?

MR. LISSELL: No.

CO-CHAIRMAN SAEGER: What is the depth of that hole?

MR. LISSELL: About ⅜-in.

CO-CHAIRMAN SAEGER: Some years ago, working on the development of the compression test apparatus, I was interested in possible correlation of deformation and compression strength with regard to flow. In your work, you correlated everything from the deformation of the specimen to flow. I found that if sand is kept to its best working temper to establish its strength, varying clays (we will say bentonite which is considered a plastic clay, as compared to some other type of clay more or less a fire clay variety), there will be more deformation with the plastic clay as compared to the fire clay, and there is enough difference to give a correlation between deformation and flow.

MR. LISSELL: It seems to me that you can get a correlation if the moisture is kept below temper, but as soon as it goes above temper, the specimen will start to sag and bulge in the deformation apparatus. Under these conditions, it is not a straight correlation.

CO-CHAIRMAN SAEGER: I mean, establish the best working temper for

a given sand with a given clay content and then see how it bulges before it breaks.

CHAIRMAN DUNBECK: I think that the work done at Michigan State College shows that there is a difference in the deformation of the mold, or a change in the size of the cavity, depending on the type of clay or sand used.

M. E. GANTZ[3]: We have been rather disappointed in the Dietert test of flowability for the reason that, using synthetic sand, it is possible to get enough bentonite into the sand so that when it is tested for flowability, the flowability will be very high, and yet when the specimen is examined after the test is finished, it can be readily seen, at the bottom of the specimen, that it did not fill out very well.

With the sand of grain fineness of 60-65, containing three to five per cent bentonite, a bridging effect of the sand is obtained which is not indicated on the Dietert machine. Would that disadvantage be eliminated by this type of test?

MR. LISSELL: I would say that this type of test is quite limited. It cannot be used with a binder of high strength plasticity, because this test is not supposed to be used for compressibility. As I said before, I don't think there is much of an elastic flow with a plastic binder.

MR. PRAGOFF: The Subcommittee on Flowability of the Foundry Sand Research Committee, of which I am a member, is very much interested in work of this sort. We have only recently oriented our thoughts as to what would be desirable tests in order to apply such information to everyone's problem.

As Mr. Lissell has pointed out, the relative flowability of a very flowable sand may be significant to a certain type of core or molding sand mixture, and it may have no significance to someone working at the other end of the scale. We are, however, endeavoring to set up a program, and we hope to have something to report later on, starting with sand which has not been put into a specimen first, and, possibly, while applying force to that specimen, we shall be able to learn more about flowability. We may have to modify our methods of testing to give information that is applicable over the whole range. It is always a problem to attempt to set up a method of physical testing. It is necessary to compromise between the ideal, from the academic point of view, and the practical, from the foundry's point of view, and we hope to be able to make progress on it before long.

MR. LISSELL: It seems to me that in determining flowability for, for instance, blowing sand, the elastic flowability, what we call the true flowability, is the important thing, and our compression test will not give an indication as to that property. On the other hand, a steel molding sand, especially for dry sand molding, where the plasticity is very high, would need a testing method which would indicate compressibility of the sand rather than the elastic flow. It is difficult to find one testing machine that will give information about both.

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[3] American Magnesium Corp., Cleveland, O.